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by

PANEL ON NEW PROCESSES FOR MACHINING AND GRINDING

of the

MINERALS AND METALS ADVISORY BOARD

NEW PROCESSES FOR MACHINING AND GRINDING

This Report Prepared and Submitted to the Chairman of the Research and Development Board under Contract DA-49-025-sc-83, Between the Department of Defense and the National Academy of Sciences.

Division of Engineering and Industrial Research
Division of Geology and Geography
National Academy of Sciences
National Research Council
Washington 25, D. C.
January 18, 1952

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I am forwarding to you herewith a report on "New Processes for Machining and Grinding" which has been submitted through the National Academy of Sciences-National Research Council to the Chairman of the Research and Development Board. The contents, conclusions, and recommendations are solely those of the Minerals and Metals Advisory Board and its Panel and staff on New Processes for Machining and Grinding.

Very truly yours,

Francis C. Frary

Francis C. Frary, Chairman
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Board

Enclosure

PREFACE

The Minerals and Metals Advisory Board, through the National Research Council, is distributing this report of the Panel on New Processes for Machining and Grinding to those agencies and individuals who have contributed to, or who will be concerned with the subject matter. This report is a report under Contract DA-49-025-sc-83 between the Department of Defense and the National Research Council, which was negotiated at the request of the Research and Development Board.

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REPORT

on

NEW PROCESSES FOR MACHINING AND GRINDING

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Washington 25, D. C.
February 6, 1952

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SUMMARY

The potential values of new processes for machining and grinding have been evaluated with the conservation of diamond bort being of special interest. Some of these new processes appear promising as methods for conserving diamond bort when grinding sintered carbides; and they appear to offer promise for forming and finishing other hard-to-machine materials besides carbides. The electro-mechanical and electro-chemical types of processes are limited to shaping and finishing electrically conducting bodies such as metals and carbides. Abrasive types of methods, including diamond wheel grinding and ultrasonics, are capable of cutting all hard materials.

Eight specific important operations, where new processes for machining and grinding may be needed, have been emphasized in this report. For each of these operations, at least one of the new processes appears to offer possibilities for satisfactorily doing the job; and for shaping and finishing dies, two of the processes are in commercial use. Most of the diamond bort is consumed in shaping, finishing, and sharpening cemented carbide tools, such as single point tools, milling cutters and dies.

Except for shaping and finishing dies, none of the new processes are in actual commercial use; nor are there fully proven designs available for immediate use in manufacturing machines to meet a shop demand toward saving bort. However, there are machine designs available for practical evaluation of these processes and of the results of using them to shape or sharpen materials and tools. A limited number of machines is becoming available for practical evaluation. Before substantial savings of diamond bort can be realized, there must be thousands of commercially operable units based on one or more of the new processes. At the present stage of development, some of the processes appear

capable of using existing machine units without extensive modification.

Most of the new processes considered are worthy of more intensified research and development, leading as rapidly as possible to large scale industrial testing. For essentially every application, it will be necessary to carry out performance tests under conditions of shop operation, not only on the new cutting machines, but also on the as-shaped or as-finished items. Concurrent with performance tests, research and development on machine improvements and on fundamentals should proceed in a more intensified manner.

To assist in pointing out the direction of effort for making these new processes commercially available as soon as possible, four recommendations have been formulated. These recommendations are concerned with: (a) the military's activity; (b) industrial research and development; (c) an educational program; and (d) means of obtaining effective liaison and coordination.

1. INTRODUCTION

Diamond wheel grinding has for some time been the only practical method for shaping and finishing cemented carbide tools and tungsten carbide projectile cores. These job items account for approximately 70% of the diamond bort consumption in this country. At the present time, imports and reclamation of diamond bort are limited and although there may be some increase, these might not be sufficient to produce the tools and military end items in the event of a substantially increased preparedness or mobilization program.* In addition, many new military items, which involve hard-to-machine materials, are being developed, and the anticipated rate of production of these is very large. This will make the diamond bort procurement situation even more serious.

Therefore, there is a need for the development of new processes that do not require diamond bort. The basic phenomena of several such processes are known, but their status with respect to specific important applications must be evaluated. Descriptions of these new techniques and evaluation of their potential values with respect to these important operations or job items is the subject of this report. Also, some conclusions have been reached on the direction of research and development to bring these processes as rapidly as possible into large scale industrial testing and use. These conclusions are based on understandings resulting from a Panel meeting held on December 12 and 13, 1951, in Washington, D. C. Members of this Panel included scientific and technical specialists in the fields of grinding, machining, electrochemistry and cemented carbides.

2. DESCRIPTION OF NEW PROCESSES

Excluding various ramifications of methods employing bonded or coated abrasives, there are known to be several processes under development in this country which might be substitute methods for diamond wheel grinding operations or

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* See Appendix II, "The Diamond Bort Supply Problem."

have possibilities for machining and grinding hard-to-machine materials that are badly needed for our preparedness program. These techniques include (1) the electrolytic process, (2) the electro-sparking process, (3) the electro-arcing process, (4) the ultrasonic process, and (5) various combinations of the preceding four.

The following summarizes the essential descriptions and features of each of the processes, as currently practiced or being developed in the United States.*

2.1. The Electrolytic Process**

Electrolytic grinding is usually performed by a revolving metal disc cathode in close proximity to an anodic workpiece while an electrolyte is applied to the disc and workpiece in the same manner as a coolant is applied to a grinding wheel and work. The method is usable for removing stock from electrically conducting bodies such as metals or metal carbides. It appears especially suited for removing stock from large surfaces, but its applications are limited where very small surfaces need be ground or for drilling of small diameter deep holes.

The electrolytic process utilizes steady direct current and a highly conducting electrolyte. Relatively low voltages of less than 25 volts and usually between 16 and 18 volts are used. It is characterized by low local heating and essentially no consumption of the cathode. In this process a true electrochemical action takes place in accordance with Faraday's Law. With fixed current density, the rate of stock removal, in terms of volume per unit of time, is proportional to the effective area of the work exposed to the electrolytic action. Cathode-anode spacing and polarization effects appear to be critical factors in the electrolytic process, particularly for shaping or finishing cemented carbides.

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* Similar processes are being developed in foreign countries. See Appendix V, "European Activities on Electro-Processes for Machining and Grinding."

** See Appendix VI, "The Electrolytic Process for Shaping Metals and Metal Carbides."

2.2. The Electro-Sparking Process*

In the electro-sparking method, stock is usually removed by making the work one of the electrodes in a properly designed circuit. Rapidly pulsed current (usually oscillatory) of the spark discharge type is passed between the work and the other electrode in a dielectric fluid. The method is used for removing stock from electrically conducting bodies such as metals or metal carbides and is especially suited for forming small diameter, deep holes of any shape.

The electro-sparking process is characterized by relatively high electrode consumption. Local heating is not experienced under ideal operating conditions. The range of voltage usually employed is between 40 and 300 volts. In a pure electro-sparking process the electro-discharge is initiated by the voltage across the dielectric. The process is electro-mechanical and not electrochemical (as the electroyltic process). The stock is removed by a sparking action and the metal or metal carbide particles are carried away suspended in the dielectric fluid.

2.3. The Electro-Arcing Process

Cutting by the electro-arcing process is performed by making the work anode with an arc maintained between the work and the cathode. The method usually utilizes pulsating direct current using a moderately conducting electrolyte such as water glass solution. It is especially suitable for rapid cut-offs of hard metals and carbides and may be faster than existing cut-off procedures. However, in a pure electro-arcing process, somewhat rough finishes are obtained.

In the electro-arcing process, low voltages of less than 25 volts are usually used. For a pure electro-arcing process the electro-discharge is initiated by contacting the electrodes and current is carried by vaporized metal ions. The process is commonly characterized by the deposition of some non-conducting film (such as silica) on the work and high local heating is evidenced with moderate consumption of the cathode. As in the electro-sparking method, electro-arcing is essentially

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* See Appendix VII, "Electro-Sparking Process for Shaping Carbides."

electro-mechanical in nature, in that the metal or metal carbide is not removed by an electrochemical reaction.

2.4. The Ultrasonic Process*

As differentiated from the electro-processes described above, the ultrasonic process does not utilize electric current directly for stock removal. Cutting or stock removal is accomplished by abrasive action at high frequency and low amplitude. Unlike the electro-processes, the ultrasonic technique grinds non-metal or non-electrically conducting bodies as well as electrically conducting materials.

In the ultrasonic process, the cutting or grinding tool is usually vibrated in the frequency range from 16,000 to 29,000 cycles per second through an amplitude of not more than a few thousandths of an inch. The abrasive, which is usually 280-grit boron carbide, is carried in water to the tool and work. Other grit sizes and abrasive compounds, such as aluminum oxide and silicon carbide, may be used but these do not last so long as boron carbide. Consumption of the tool occurs during grinding and machining.

2.5. Combination Processes

In addition to the four processes described above, machines may be devised for effecting combinations of some of these four processes. For example, the combination of the electrolytic and diamond wheel grinding has been tested and is being developed. For this combination process, a metal bonded diamond wheel must be used for the cathode. The diamond particles act as insulating spacers, separating the work from the wheel, and as scrapers.

Machines have been tested and are being designed for effecting machining and grinding by electrolytic and/or electro-arcing actions. The same electrolyte or more than one electrolyte might be used by the same equipment which will serve for either the electro-arcing or the electrolytic process.

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* See Appendix VIII, "Ultrasonic Grinding and Machining of Both Metals and Non-Metals."

Electro-arcing, electro-sparking, and electrolytic actions might occur simultaneously during a grinding or cutting operation. Machines predominantly operate on the basis of one of the processes but there may be other process mechanisms superimposed. The superimposition of more than one mechanism or process in a cutting or grinding operation could markedly alter the results obtained.

The ultrasonic technique might be used in combination with one of the electro-processes such as the electrolytic one. However, this has not as yet been tested.

3. POTENTIAL APPLICATIONS OF NEW PROCESSES

To evaluate the applicability of new processes for machining and grinding, it is necessary to consider the pertinent or important job items or operations. The first consideration in the selection of job items is the current use of diamond bort for performing the operations in accordance with present day practices. These operations involve principally diamond wheel grinding. In addition to those operations that currently use diamond bort, other finishing and forming operations of hard-to-machine materials, which are needed for our preparedness program, must be evaluated. Diamond wheel grinding or some other form of diamond cutting might be suitable for some of these latter job items, but if they are to be produced in the large quantities anticipated for our preparedness program, there aren't enough diamonds in the world to do the job because the diamond bort supply is hardly adequate to perform the operations currently underway.

On the following page are tabulated eight important machining and grinding type operations, which cover the important job items described above. They are listed in order of current diamond bort consumption and account for approximately 74% of the diamond bort consumed in the United States. This tabu-

TABULATION OF IMPORTANT MACHINING AND GRINDING OPERATIONS AND ESTIMATED APPLICABILITY OF METHODS

Job Item or Operation	Percent Use of Diamond Bort**	Applicability of Methods*				
		Diamond Wheel Grinding	Electro-lytic	Electro-sparking	Electro-arcing	Ultra-sonic
1. Sharpening of single-point tools	30	A	B	B***	C	B***
2. Grinding single-point tool chip breakers	20	A	B	B	C	B
3. Sharpening milling cutters and broaches	15	A	B	B	C	B
4. Grinding projectile cores	5	A	B	B	C	B
5. Shaping and finishing dies	4	A	D	A	D	A
6. Forming of turbine bucket attachments	--	B	B	B	C	B
7. Rifling of gun barrels	--	B	C	B	C	B
8. Machining and grinding of compressor discs	--	B	B	B	C	B

* A. In use on production scale.

B. Appears applicable; promising but limited experimental data to date.

C. Questionable applicability; not promising but might be developed to be promising.

D. Limited applicability or not applicable; not usable in present state of development.

** Approximate percentage of total diamond bort currently being consumed in the United States. All diamond wheel grinding consumes about 85% of the bort and the operations considered account for 75% of the bort. The remaining 10% is used for a multiplicity of operations.

*** Not applicable for off-hand grinding but appears applicable for machine grinding.

lation indicates the estimated applicability of the new machining and grinding methods, including diamond wheel grinding. These applicability ratings are based on current knowledge of methods as being developed in this country and they may change as new developments progress. The following describes in more detail the potential applications of the new machining and grinding processes as related to each of the eight operations or job items as listed in the table.

3.1. Sharpening of Single Point Tools*

Single point tools considered in this report are made of cemented carbides mounted on a steel shank. Sharpening of these single point tools is usually performed by flat off-hand grinding operations using diamond grinding wheels. This operation accounts for approximately 30% of the diamond bort consumption in this country, and as such is the largest single consumer of diamond bort. In addition to usually being a flat off-hand grinding type of operation, the steel shank is usually ground separately from the cemented carbide with the use of an aluminum oxide grinding wheel. The effective area usually ground ranges from 0 to 1/2 square inch and small depths of metal are removed. The type of performances of resinoid bonded diamond wheels is shown in an appended report where the side of a cup wheel does the work.** Sharpening of single point tools usually involves removal of stock from a flat surface although there may be occasional need for cut-off type of operations.

The specifications for as-sharpened single point tools are not very exacting, but they usually require that no cracks be visible at 200 magnification and that the surface finish be better than 50 rms micro-inch.*** Sharp edges are a prime requirement but there is no accepted specification on the sharpness of a tool, and the only way of judging the suitability is through performance.

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* See Appendix I, "Grinding Requirements of Carbide Fabricators and Users."
** See Appendix III, "Performance of Diamond Wheel Grinding."
*** rms - root mean square roughness in micro-inches as measured by a profilometer.

If the operation of sharpening single point tools is limited to flat off-hand grinding, then only the electrolytic method or combinations of the electrolytic method with abrasive grinding appear promising with respect to applicability (See tabulation on Page 6). The process as currently known can be an off-hand grinding operation by converting conventional metal bonded diamond wheel grinding machines through the addition of auxilliary equipment such as a rectifier and an electrolyte pump (Appendix VI). Eight conventional types of grinding machines are now being converted to electrolytic grinding and these machines will operate to test the sharpening of single point tools utilizing a combination of diamond wheel scraping and electrolytic action. The electrolytic method produces no cracks and meets the finish specifications at all speeds of metal removal. Commercial performance and cost of the operation are indefinite and must yet be established.

If sharpening single point tools is not limited to flat off-hand grinding, then the electro-sparking technique and the ultrasonic technique appear applicable as shown in the table on Page 6. However, neither of these processes are, at the present time, adaptable to off-hand grinding but they can be mechanized in machine grinding. Electro-sparking methods have questionable cutting time for sharpening single point tools. The equipment is somewhat more expensive than for the other methods and the operating cost is dependent on rate of cutting and finish desired. For finishes of 10-20 rms micro-inch the electro-sparking techniques become more expensive. No machines are at present available for sharpening single point tools by electro-sparking methods and ordinarily about one year would be required for production of machines for this purpose. The ultrasonic technique produces no cracks or damage and meets the finish specifications required for single point tools. However, the sharpness of the edges as produced by the ultrasonic method have yet to be tested. Sixteen ultrasonic machines are currently available for further test work on machine grinding of single point tools (Appendix VIII).

The electro-arcing process has been tested principally as a cut-off method but it produces rough finishes that do not meet specifications for single point tools. However, experimental work is planned on machines designed to operate on a combination of electro-arcing and electrolytic actions and this might prove promising for sharpening single point tools.

3.2. Grinding Single Point Tool Chip Breakers

Some cemented carbide single point tools require chip breaker grooves to be ground in them back of the cutting edge. Grinding these chip breakers accounts for approximately 20% of the currently consumed diamond bort. The conventional method for grinding chip breakers is by the use of diamond grinding wheels (Appendix I).

The grinding of chip breakers is not a flat off-hand grinding operation but requires machine grinding. The form is trough shaped and the grinding operation is for only small depths. Appreciably smaller effective grinding surface areas are present for forming chip breakers than for sharpening single point tools, being in the order of from 0 to 0.2 square inch. The same type of specifications on chip breakers hold as for single point tools. There must be sharp edges, no cracks at 200 magnification, and better than a 50 rms micro-inch finish.

Of the new processes, the ultrasonic technique appears especially applicable for grinding single point tool chip breakers (Appendix VIII). This technique performs and produces a finished article in much the same manner as described for sharpening single point tools, but the potential cost of grinding chip breakers appears better than for sharpening single point tools by the ultrasonic process. In addition, a special shaped chip breaker groove might be inserted in a single inexpensive manner by the ultrasonic technique. However, the sharp edges have yet to be tested.

As shown in the tabulation on Page 6, the electrolytic and electro-sparking processes appear applicable to grinding single point tool chip breakers. The electrolytic method meets the finish specifications, and as in the single point tool sharpening, conventional grinding machines might be converted. But because grinding chip breakers is a machine grinding operation, the conversion will be more extensive. At the present time one machine is being converted to operate by a combination electrolytic and diamond wheel grinding. The rate of metal removal by the electrolytic process for forming chip breakers is not so favorable as for sharpening single point tools because of smaller effective grinding areas involved. The electro-sparking technique can be mechanized for forming chip breakers, but the cutting time is questionable, the cost of the operation is dependent on the rate of cutting, and the technique is more expensive for the better finishes in the range between 10 and 20 rms micro-inch. Although at least seven electro-sparking type machines are now available, about one year will be required for construction of machines for adaptation to forming chip breakers.

The electro-arcing process appears to be of questionable applicability for grinding chip breakers because the finish is rough and damage is possible. However, a combination of the electro-arcing process with the electrolytic process in one machine may prove promising.

3.3. Sharpening Milling Cutters and Broaches

Milling cutters or broaches are made with sintered carbide teeth and consist, in effect, of several single point type tools mounted in a body. Each tooth of the milling cutter or broach is usually ground separately, using diamond grinding wheels in a special setup. The teeth are ground to a small depth and the effective area of grinding is between 0 and 1/2 square inch. Sharpening of milling cutters and broaches accounts for approximately 15% of the total diamond bort consumed in this country.

Specifications required on as-sharpened milling cutters and broaches are similar to those for as-sharpened single point tools. That is, no cracks must be visible at 200 magnification, sharp edges must be effected, and the finish must be better than 50 rms micro-inch.

Because the operation is machine grinding, diamond wheel grinding is somewhat more costly than for sharpening single point tools. A cup wheel is usually used for this operation.

The tabulation on Page 6 shows that the electrolytic, the electro-sparking, and the ultrasonic processes appear applicable for sharpening milling cutters and broaches, but there are no machines available for testing this operation since it requires a special arrangement and setup. The electro-arcing process is of questionable applicability for this operation. For each of the new methods, the conclusions derived on sharpening single point tools are expected to hold for sharpening milling cutters and broaches.

3.4. Grinding Projectile Cores

Projectile cores are made of cemented carbides weighing from 4 to 12 pounds and the grinding operations are usually flat base or ogive type. Unlike the sharpening of tools, the effective area of grinding is large, namely, between 2 and 10 square inches. Grinding of projectile cores accounts for approximately 5% of the diamond bort consumption in this country.

All of the new methods (with the exception of the electro-arcing process) appear applicable or promising for grinding projectile cores but very little, if any, experimental work has been done to be able to evaluate these new techniques as applied to the grinding of projectile cores. If cemented carbide type projectile cores are to be produced in much larger quantities for our preparedness program, then these new processes should be tested for this application since there may not be sufficient diamond bort to do the job.

3.5. Shaping and Finishing Dies

Many dies of a variety of shapes are made of cemented carbides, and they include wire drawing dies, blanking dies, and punching dies. Approximately 4% of the total diamond bort consumption is used for shaping and finishing these dies (Appendix I).

The table on Page 6 shows that, in addition to diamond wheel grinding, the electro-sparking process and the ultrasonic process are in commercial use. There are currently six mechanized electro-sparking type machines in use for shaping and finishing dies. The equipment is somewhat expensive and the cost is dependent on the rate of cutting and the finish desired. The ultrasonic technique has sixteen machines in operation and incurs no cracks or damage to the finished dies. Both the ultrasonic and the electro-sparking processes are used in operations for all but the final lapping, and they are more versatile than diamond wheel grinding. The economics on these processes appear satisfactory because they are in competition with diamond wheel grinding. For producing shaped holes, these techniques are more suitable than diamond wheel grinding.

The electrolytic method and the electro-arcing method appear to be of limited applicability or are not applicable for shaping and finishing dies (See table on Page 6).

3.6. Forming of Turbine Bucket Attachments*

Turbine bucket attachments are usually made of nickel-cobalt super alloys or cemented carbides of intricate shapes with up to 2 square inches of shaping area. Stock removal is from light to heavy, from .05" to 1/2". The surface finish must be less than 25 rms micro-inch, tolerances are as close as 0.0003" and shaping must be very close. At the present time grinding of the alloy types is accomplished by such means as crush form grinding, using aluminum oxide

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* See Appendix IV, "The Forming of Gas Turbine Engine Blade Fastenings."

wheels. For sintered carbides, such as cemented titanium carbide, no method for quantity production is, as yet, established. Diamond form grinding does not appear promising because it is too slow and too expensive. If the number of turbine blades required is in the hundreds of thousands per month, forming time required per attachment must be only a few minutes.

The electro-sparking, ultrasonic, and electrolytic techniques appear promising for forming of turbine bucket attachments, at least for part of the operations. The electro-arcing process appears of questionable applicability because it cannot meet finish and tolerance specifications.

3.7. Rifling of Gun Barrels

In the event of much increased production of machine guns for our preparedness program, faster and better methods for machining and grinding will be very helpful and the new processes may find their applications in the field of rifling hard-to-machine materials used in gun barrels or gun barrel liners.

As shown in the table on Page 6, the electro-sparking and ultrasonic techniques appear applicable for rifling of gun barrels. The electrolytic and electro-arcing processes are of questionable applicability.

3.8. Machining and Grinding of Compressor Discs

There is considerable research and development work under way to utilize high strength titanium alloys (more than 125,000 psi) in jet engine components, particularly for compressor discs. However, there has been considerable difficulty experienced in machining and grinding these titanium alloys by conventional methods. Lathe tools, for example, seize and wear rapidly, and aluminum oxide grinding wheels are consumed very fast. Therefore, conventional machining and grinding operations on these titanium alloys are slowed down considerably.

Diamond wheel grinding is applicable for this purpose, but it may be too expensive and slow. The new processes, with the possible exception of the electro-

arcing process, appear applicable and promising. The electrolytic process in particular appears especially applicable for machining and grinding titanium alloy compressor discs.

4. CONCLUSIONS

Most of the new processes and the combinations thereof appear promising as methods for conserving diamond bort for shaping and finishing sintered carbides and for performing operations on other hard-to-machine materials for important military end use items. Performance and costs for these new processes are not as yet well established.

The electrolytic process appears very promising as a means for flat offhand grinding as applied to sharpening of single point tools. Since this application is the largest single consumer of diamond bort, the rapid development of this process for sharpening of single point tools offers possibilities for substantial relief of diamond bort. However, there are tens of thousands of diamond wheel grinders used for sharpening single point tools, and it would be necessary to bring in or convert at least thousands of machines to show any appreciable effect. Additional experimental work must be completed before these machines are ready for mass production.

The second most prolific consumer of diamond bort is the grinding of single point tool chip breakers. The ultrasonic technique appears to be adaptable for this purpose. Additional experimental work is necessary to properly appraise the method.

The sharpening of milling cutters and broaches and the grinding of projectile cores account for a substantial consumption of diamond bort. The electrolytic, electro-sparking, ultrasonic processes, and combinations of them, look like possibilities for these applications; but experimental programs in these fields have yet to be started.

On the forming of cemented carbide turbine bucket attachments and machining and grinding of titanium compressor discs, no commercial methods have been established and it may be necessary to develop some of the new processes at a very rapid rate to meet the demands of possible increased production for the military. The electro-sparking and ultrasonic processes appear applicable for forming turbine bucket attachments and rifling of gun barrels, the electrolytic process appears promising for machining and grinding of compressor discs.

None of the new processes are in actual commercial use except for shaping and finishing dies. However, a limited number of machines, based on these new processes, are becoming available for practical test work. For producing tools such as single point tools, chip breakers, milling cutters and broaches, it will be necessary to carry the development work on these new processes through fairly extensive performance tests. These tests should not only be made on the machines but also on the tools themselves in order to adequately establish them as production units. At the same time research and development on machine improvements and on learning more fundamentals should proceed in a more intensified manner. The performance tests might best be done in production shops and eventually they must be done there. However, it may be worthwhile to design special programs for accelerated performance tests to exploit the methods as rapidly as possible. Performance tests and other research and development should be carried out mainly by industry who have the real need for these new processes.

5. RECOMMENDATIONS

Recognizing that several new processes for machining and grinding appear to offer promise both for saving diamond bort and for shaping materials urgently needed for our preparedness program, and that the rate of development effort should be accelerated to bring these methods into form suitable for large scale testing, it is recommended that:

5.1. The Army, Navy, and Air Force explore the application of these processes to relieve potential bottlenecks or shortages and allocate or seek funds in the furtherance of these objectives where government incentive is required. In the event that the military services are satisfied that the development of a particular technique is essential in the production of military weapons and equipment, the government will have a high incentive to participate in programs which will accelerate the development of these techniques. One of the fields which can be profitably and efficiently sponsored by government agencies is in the area of fundamental and basic research. Fundamental and basic programs will provide essential background information to industry for their machine development work after industry outlines the type of information which would be most helpful.

5.2. Industry should be encouraged to accelerate its efforts in research, and in machine developments, and in performance tests towards bringing these processes into industrial use as soon as possible. Government can assist industry in a number of ways: (a) by making available needed equipment and supplies; (b) by calling attention to urgently needed military end items which might require new machining and grinding processes; and (c) by issuing contracts to industry for specific end item prototypes requiring the new processes.

5.3. An educational program should be undertaken. Tool users and others should be made aware of the critical diamond bort supply problem in relationship to their operations. The wasteful use of diamond bort should be discouraged. In

addition, publicity should be given to the new promising processes which might in time relieve the diamond bort shortage. The educational program may take on a variety of forms and could be handled in part by a proper government agency, such as NPA, which is primarily concerned with the diamond bort supply problem. Others, such as editors of trade journals, technical societies, and specific industrial organizations, should be asked to participate in any educational program.

5.4. A committee should be set up to disseminate present and future pertinent information dealing with machining and grinding processes for use of governmental agencies. It appears important that there be some centralization of liaison and coordination so that the different government agencies can be properly informed and advised with a minimum of unnecessary duplication of effort. For example, the Office of Technical Information Service, Commerce Department, or the Armed Services Technical Information Agency, Department of Defense, are in a position to undertake this assignment.

6. APPENDICES

At the Panel meeting, held on December 12 and 13, 1951, several reports, bearing on the evaluation of new processes for machining and grinding, were presented by individuals at the request of the Minerals and Metals Advisory Board of the National Research Council. These reports are appended as follows:

Appendix I - "Grinding Requirements of Carbide Fabricators and Users" by John C. Redmond, Kennametal, Inc., Latrobe, Pa., and Ford C. Ritner, Carboloy Dept., General Electric Company, Detroit, Michigan.

Appendix II - "The Diamond Bort Supply Problem" by Max N. Felker, NPA, Washington, D. C.

Appendix III - "Performance of Diamond Wheel Grinding" by H. W. Wagner, Norton Company, Worcester, Mass.

Appendix IV - "The Forming of Gas Turbine Engine Blade Fastenings" by John C. Redmond, Kennametal, Inc., Latrobe, Pa.

Appendix V - "European Activities on Electro-Processes for Machining and Grinding" by L. H. Metzger, Super-Cut, Inc., Chicago, Ill.

Appendix VI - "The Electrolytic Process for Shaping Metals and Metal Carbides" by George Keeleric, United Drill & Tool Corp., Chicago, Ill.; Howard T. Francis, Armour Research Foundation, Chicago, Ill.; and Charles L. Faust, Battelle Memorial Institute, Columbus, Ohio.

Appendix VII - "Electro-Sparking Process for Shaping Carbides" by Ian McKechnie, Chrysler Central Engineering, Detroit, Mich., and D. F. Dickey, Firth Sterling Steel and Carbide Corporation, Pittsburgh, Pa.

Appendix VIII - "Ultrasonic Grinding and Machining of Both Metals and Non-Metals" by Arthur Kuris, Cavitron Equipment Company, New York, N. Y.

Appendix IX - "Electro-Erosive Machining of Hard Metals and Carbides" by I. Weber and G. F. Nordblom, Frankford Arsenal, Philadelphia, Pa.

APPENDIX I

GRINDING REQUIREMENTS OF CARBIDE FABRICATORS AND USERS

By John C. Redmond, Kennametal, Inc., and
Ford C. Ritner, Carboloy Dept.,
General Electric Co.

I. INTRODUCTION:

Cemented carbide compositions have come to be widely recognized and accepted as excellent for a wide range of industrial cutting and wear applications. However, it is doubtful if American industry's absolute reliance on carbide tools is always recognized. Most machining operations which are now done with carbide would require several times the machine tools and manpower to produce equivalent volume. In these days of the shortage of certain elements, it is of interest that a pound of tungsten will do 70 to 100 times as much work in the form of tungsten carbide as in high speed steel. There are many important machining operations which can not be done by any other means.

Commercial cemented carbides are products of powder metallurgy, made of very finely divided carbide particles of the refractory metals, cemented together by a metal or alloy of the iron group, forming a body of great hardness and high compressive strength.

Cemented carbides were first used for wire-drawing dies, from which the application expanded to include all types of drawing dies for round and irregular shapes, and cutting tools for machining all kinds of materials. In addition, cemented carbides have been used for machine and instrument parts and for a wide variety of products where high rigidity and resistance to wear are important.

In general, cemented carbides come under the two broad classifications that follow, depending on their uses.

1. The straight tungsten carbide with cobalt binder is used in tools for cutting cast iron, nonferrous metals and nonmetallic materials; and in dies for drawing wire, bar, tube and sheet metal, and for blanking; as well as for machine parts where resistance to wear is important.

Composition Range:

Tungsten Carbide..... 80-97%

Cobalt..... 3-20%

Hardness Range:

84-93 Rockwell "A"

Density Range:

13.40-15.35 grams/cm^3

Transverse Rupture Strength Range:

125,000-425,000 psi

2. The steel-cutting grades consist largely of tungsten carbide with additions of titanium carbide or tantalum carbide or both, or of columbium carbide. These added constituents produce a material that resists cratering better than the straight tungsten carbide grades. ("Cratering", caused by the hot steel chip, is the formation of a cavity in the top surface of the carbide blank, slightly behind the cutting edge.)

Composition Range:

Tungsten Carbide..... 61-93%

Cobalt..... 3-25%

Tantalum Carbide..... 1-27%

Titanium Carbide..... .15-32%

Hardness Range:

84-93 Rockwell "A"

Density Range:

8.80-15.20 grams/cm^3

Transverse Rupture Strength Range:

100,000-325,000 psi

Basically, the process consists of preparing the powder carbides of tungsten, titanium or tantalum; mixing one or more of these carbides with a binder, such as cobalt powder; pressing the blended powder into compacts of desired form; and sintering molded shapes to achieve consolidation.

Compacting and Sintering. - The prepared powders are formed into shapes for commercial use by (1) cold pressing, followed by sintering; (2) by hot pressing, during which the pressing and sintering are done simultaneously; (3) by extrusion, in this process the prepared powders are mixed with a plasticizer. The plastic material is extruded through a die, baked at low temperature, pre-sintered and sintered.

Applications. Cutting Tools. - Grades of commercial cemented carbides are available to meet almost any machining requirement.

Ordinarily, where cemented carbides are used in the construction of tools, a small piece of the carbide material is brazed or fastened mechanically to a steel shank that provides a rigid support under the cutting edge.

The grinding or sharpening of cemented carbide tools is not particularly difficult so long as certain precautions are observed. Silicon carbide and diamond-impregnated grinding wheels are used to grind the carbide, but the grinding of the steel shanks to which the carbide is attached, is done best with an aluminum oxide wheel. The customary procedure is to grind the portion of the steel shank that is not close to the carbide tip, with an aluminum oxide wheel, and then to grind the carbide with the silicon carbide or diamond wheel.

Cemented carbides may be used for cutting operations ranging from light finishing cuts at high speeds and light feeds, to heavy cuts with coarse feeds and slower speeds. Interrupted cuts on steel and other materials are common with tools designed for the purpose.

Cemented carbides are used in the following tools:

Single point	Solid twist drills for nonferrous materials
lathe tools	Hi-Brinell drills
Reamers	Small solid circular saws and large carbide-
Counterbores	tipped circular saws
Spot facers	Milling cutters of all shapes, sizes and kinds
Counter sinks	Shear blades
Facing tools	Files, flat and rotary
Boring tools	Dental burrs
Turning tools	Planer tools
Threading tools	Bending tools
Fly cutters	Gage contact points
Form tools	Spinning tools
Broaches	Hand scrapers
Core drills	Brinell balls
Boring bars	

Mining Tools. - A rapidly developing and important recent use for carbides is in mining tools. As in the cutting tools, the carbide forms an insert in the cutting edge. Mining tools are universally of brazed construction so, as in the case of brazed cutting tools, the grinding of a composite structure is involved. While diamond wheels are frequently used to size the blanks in the fabrication of the tools, silicon carbide wheels serve for resharpening operations.

Types of mining tools are as follows:

Coal cutting machine bits

Auger bits

Rotary drill bits

Percussion bits

Core bits

DIES. - The first commercial application of carbide dies was for the hot drawing of tungsten and molybdenum wire. The usage expanded rapidly and within a few years, carbide dies were generally employed for the cold drawing of wire made of steel, copper, aluminum and other materials. Today a large percentage of wire, rod and tubing smaller than $3\frac{1}{2}$ in. in diameter is produced through these dies. In addition, considerable high speed wire is drawn hot, using carbide dies.

Besides the application in the wire, bar and tubing field, cemented carbides are employed largely for the cold extrusion and heading of parts such as bolts and nails, and for the nosing of shell forgings.

Cemented carbides are used extensively in the blanking of steel, aluminum, and like metals and in the cupping, drawing and redrawing of steel metal parts in sizes from small eyelets to cylinders 10 in. in diameter.

Carbide-tipped mandrels for sizing the inside diameter of all types of tubing, produce tubes with a fine finish inside and hold the wall thickness and dimensions of the hole within close tolerances.

WEAR. - The practical application of cemented carbide for purposes of shaping materials both with and without cutting, is attributed to the properties of high hardness and great compressive strength required of a material to resist wear. During these operations for changing the form of materials, very high pressures are involved, and high temperatures are reached at the mating surfaces between work and tool. At elevated temperatures, cemented carbides retain their indentation hardness better than other metals and alloys. After final sintering, the cemented carbides are so hard that they can be shaped only by such operations as grinding, lapping and polishing with the hardest of abrasives, and boring, turning and facing with a diamond tool. Cemented carbides are being used where wear occurs from the loss of dimensions by rubbing, fretting of assembled parts under high stresses without visible motion, and scoring from foreign abrasive

particles between mating surfaces. Cemented carbides are used also as material for pads inserted in metal forming dies; seals or glands for sump pumps; guides used in the textile industry and in wire fabrication; guides, arbors and the like in spring-forming machines; and various gages for inspection.

The following are additional applications:

- Centers for grinders and lathes
- Steady rest pads and rollers
- Centerless grinder rests
- Gagematic gages
- Sizematic machines
- Swaging dies
- Dies and plungers for molding powders
- Collets
- Ball mill slugs
- Rolls
- Knurling wheel shafts
- Spring coiling arbors, pitch tools, guides and the like
- Ways and gibs for machine tools
- Thread and wire guides
- Balls for ball valves
- Spinning and burnishing tools
- Liners for brick molds
- Chill plates for hardening thin steel
- Valve seats

II. THE GRINDING OF CARBIDE TOOLS

A. It is of interest from the standpoint of the grinding problem to follow carbide blanks from the producer through the final use. The blanks are produced by a relatively small number of companies who mold the powder to the shapes and sizes desired and sinter them. The great majority of these blanks are shipped in this form by the carbide producers who themselves fabricate only a small percentage into tools. Most tools are fabricated either by numerous small shops who specialize in tool making or by the ultimate users themselves. Thus even in the tool fabrication, by far the largest amount of grinding is done not by the carbide producer but by the tool fabricator.

However, by far the largest amount of grinding, conservatively more than three-quarters, must be done by the ultimate user of the tool in the resharpening which is required. It is estimated that the resharpenings are between five and ten per tool depending on the type and use. The amount of stock removal in each resharpening is generally considerably more than that in the original fabrication.

Thus, over 90 per cent of carbide tool grinding problem is in the hands of others than the producers of carbide blanks.*

While silicon carbide grinding wheels may be used for some of the rough grinding, diamond grinding wheels have been found to be required for the majority of these grinding operations.

B. In the production of carbide blanks or nibs, the final sintering operation involves a shrinkage of approximately 50% by volume (0.2 inch per inch dimensionally). Particularly when complex shapes are being produced, the shrinkage of a given dimension cannot be pre-determined with exactness because of the interrelation of shrinkages in other sections of the part and variables inherent in the preceding pressing and pre-sintering operations.

One of the larger carbide producers uses the following stock allowances on unground carbide blanks:

Dimension	Tolerance
Up to 3/8"	∱ 0.015" - 0.000"
3/8 thru 1"	∱ 0.020" - 0.000"
1" thru 2"	∱ 0.040" - 0.000"

The carbide industry has given and is continuing to give, much attention to processes and techniques for the production of blanks and nibs with minimum practicable stock allowances, and important advances have been made in this respect.

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* Experience of Norton Co. indicates that 24% of diamond grinding wheels used for carbide grinding go to manufacturers of tools.

C. Finished tools vary as to the dimensional requirements of the carbide blank, in brazed-on type single point tools, such as are used for turning, boring, etc., where the carbide dimensions are not of particular importance and the fabrication is largely a matter of establishing the required cutting shape, in form tools, lamination dies, etc., the dimensional requirements are exacting. Insofar as possible the fabricator selects blanks from industry standard sizes such as those shown on the attached list for single point tools.

In the manufacture of the finished carbide article, the fabricator is mainly concerned with the removal of the oversize stock allowance of the sintered blank and the provision of chip breakers and special forms to produce the tool or part to the user's requirements. The provision of chip breakers is particularly noteworthy in that it requires a large consumption of diamond grinding wheels. The application of electromachining methods to this operation should be as readily adapted to this tool grinding operation as any.

D. The following types of standard grinding machines are used in the manufacture and re-grinding of carbide tools:

Pedestal	Chip breaker
Bench	Internal
Surface	Centerless
Tool and Cutter	Profile
	Cylindrical

Of these the most important are the pedestal, bench, surface and chip breaker grinders.

Special grinding machines, frequently semi-automatic or automatic in operation have been developed for production grinding of certain types of carbide blanks and tools.

E. General requirements for process to replace diamond wheel grinding:

a. Low-cost equipment or attachments

b. Comparable stock removal or one operator run several machines

c. Reproducibility of results (size and finish)

d. Availability of required equipment and materials

e. Minimum risk of injury to carbide

f. Safety and health considerations

F. In order to give some idea of the magnitude of the grinding requirements for tungsten carbide compositions for tool and general requirements, the following very rough estimations have been prepared:

The number of blanks to be produced for 1951 is estimated at 50,000,000 or 100 per cent more than 1950. It is estimated that 25,000,000 of these blanks will be used in single point tools or twice as many as 1950.

The following is a breakdown of one major producer and is probably representative of the industry as a whole:

Single point tools (3/4" sq. shank and under)	32%
Single point tools (over 3/4" sq. shank)	8%
Special tools	15%
Mining and percussion	15%
Wear parts	10%
Standard dies	8%
Special dies	12%

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It is estimated that 60% or 30,000,000 blanks of the carbide used in the U.S.A. are in the form of standard blanks from lists such as the one referred to earlier.

Modified standard blanks and simple blanks made to user's specifications account for approximately 25% or 12,500,000 blanks of total usage.

Only approximately 15% of carbide applications require carbide blanks of complex shape such as are frequently used for form cutting tools, lamination dies, etc.

There is no basis for estimating with any degree of accuracy the quantity of carbide in cubic inches or other units which must be removed by grinding. The overall volume of the blanks will be about 3,000,000 cubic inches.

III. CARBIDE CORE GRINDING

This application of tungsten carbide compositions constitutes an important use for diamond grinding wheels though its magnitude is somewhat indefinite. The grinding of the cylindrical body is satisfactorily accomplished with silicon carbide wheels. However, the grinding of the base requires, and grinding of the ogive may require the use of diamond wheels.

IV. SUMMARY

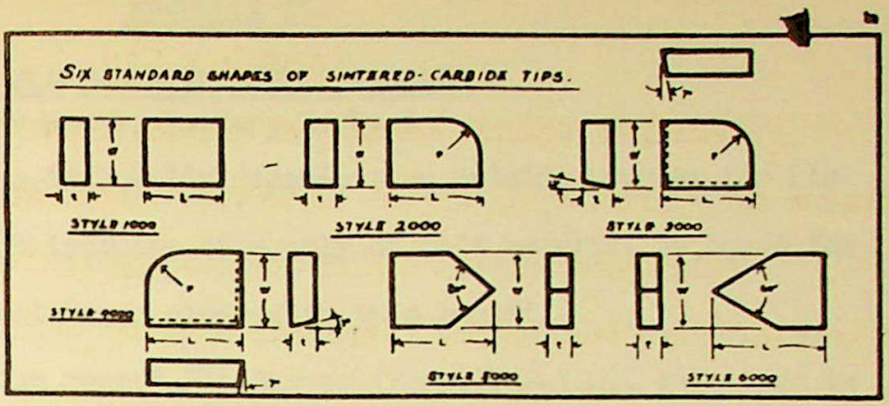
1. The largest requirement for diamond grinding wheels in connection with the use of carbide tools is for the grinding of single point tools.

2. Something like 90 per cent of the diamond grinding is done by the fabricators and ultimate users of the tools.

3. The grinding of chip breakers is an important single use of diamond wheels and any development of a substitute method would have marked influence on diamond consumption.

STANDARD SHAPES AND SIZES OF SINTERED-CARBIDE TIPS FOR SINGLE-POINT TOOLS

(These styles and shapes of sintered tips and the commercial catalog numbers have been adopted by the carbide manufacturing industries.)



Sizes and Commercial Catalog Numbers of Sintered-Carbide Tips for Single-Point Tools

Thickness t	Width w	Length l	Tip Style Numbers Stocked			
1/16	1/8	5/8	1010	2010		
1/16	3/16	1/4	1020	2020		
1/16	1/4	5/16	1030*	2030	5030	
3/32	3/16	5/16	1040	2040		
3/32	3/16	1/2	1050*	2050		
3/32	1/4	3/8	1060	2060		
3/32	1/4	1/2	1070*	2070		
3/32	5/16	3/8	1080*	2080	5080	6080
3/32	3/8	3/8	1090*	2090		
3/32	3/8	1/2	1100	2100	5100	6100
3/32	7/16	1/2	1105*	2105	5105	
1/8	3/16	3/4	1110*	2110		
1/8	1/4	1/2	1120*	2120		
1/8	1/4	5/8	1130	2130		
1/8	1/4	3/4	1140*	2140		
1/8	5/16	7/16	1150	2150		
1/8	5/16	1/2	1160*	2160		
1/8	5/16	5/8	1170*	2170		
1/8	3/8	1/2	1180*	2180		
1/8	3/8	3/4	1190	2190		
1/8	1/2	1/2	1200*	2200	5200	6200
1/8	1/2	3/4	1210†	2210		
1/8	3/4	3/4	1215	2215		
5/32	3/8	9/16	1220	2220		
5/32	3/8	3/4	1230	2230		
5/32	5/8	5/8	1240*	2240	5240	6240
3/16	5/16	7/16	1250	2250		
3/16	5/16	5/8	1260*	2260		
3/16	3/8	1/2	1270*	2270		
3/16	3/8	5/8	1280	2280		
3/16	3/8	3/4	1290	2290		
3/16	7/16	5/8	1300	2300		
3/16	7/16	13/16	1310	2310		
3/16	1/2	1/2	1320*	2320		
3/16	1/2	3/4	1330†	2330		
3/16	3/4	3/4	1340*	2340	5340	6340
1/4	3/8	9/16	1350	3350	4350	
1/4	3/8	3/4	1360	3360	4360	
1/4	7/16	5/8	1370	3370	4370	
1/4	1/2	3/4	1380*	3380	4380	
1/4	9/16	1	1390	3390	4390	
1/4	5/8	5/8	1400*	3400	4400	
1/4	3/4	3/4	1405*	3405	4405	
1/4	3/4	1	1410†	3410	4410	5410
5/16	7/16	5/8	1420	3420	4420	
5/16	7/16	15/16	1430	3430	4430	
5/16	1/2	3/4	1440*	3440	4440	
5/16	1/2	1	1450	3450	4450	
5/16	5/8	1	1460*	3460	4460	
5/16	3/4	3/4	1470*	3470	4470	
5/16	3/4	1	1475†	3475	4475	
5/16	3/4	1 1/4	1480†	3480	4480	
3/8	1/2	1	1500	3500	4500	
3/8	5/8	1	1510†	3510	4510	
3/8	3/4	1 1/4	1520†	3520	4520	
3/8	3/4	1 1/2	1525	3525	4525	
1/2	3/4	1 1/4	1540†	3540	4540	
1/2	3/4	1 1/2	1550	3550	4550	

Tolerances: [illegible] — 0.[illegible] on all tip dimension up to 3/8 in.
+0.020 — 0.000 on dimensions over 3/8 in. through 1 in.
+0.040 — 0.000 on dimensions over 1 in. through 2 ins.
Values of r are to fit the recess in shank. This radius on Styles 2000, 3000 and 4000 should be 1/8 in. for widths of tip 1/8 in. through 1/4 in.; 3/16 in. for widths of tip 9/32 in. through 3/8 in.; and 1/4 in. for widths of tip over 3/8 in.
* Signifies 1/32 oversize on width excluding tolerance.
† Signifies 1/32 oversize on length excluding tolerance.
This excess stock is provided to facilitate grinding of two opposite tip surfaces to size when for example, the tip extends entirely across the shank width.

Note: Extracted from American Standard Single Point Tools and Tool Posts (ASA B5.22-1950) published by The American Society of Mechanical Engineers. These standards also include the Standard Sizes of Shanks for Single-Point Sintered-Carbide-Tipped Tools.

These data are helpful where users prefer to assemble their own tools by brazing, or otherwise attaching, the carbide blanks to shanks. While some users prefer to buy the blanks and shanks separately, manufacturers of carbide tools also supply completely assembled tools in many forms and for many purposes.

APPENDIX II

THE DIAMOND BORT SUPPLY PROBLEM

By Max N. Felker, N. P. A

The United States is totally dependent on outside sources for its supply of diamond bort. An increase of supply of this material is hoped for but not certain and will not be considered in this report.

The results of the recent NPA Survey (Form NPAF-120), submitted to the diamond industry concerning diamond bort consumption, imports, inventories and amounts presently reclaimed for re-use, indicate a critical situation is rapidly developing and it is apparent that measures must be taken immediately toward conservation by all possible means. It is likewise apparent that the present use of bort within the carbide industry at this time precludes much further expansion of the hard metal program unless better or substitute grinding methods are developed. Since it is not the purpose of this report to do other than present the factual data known to date, of current conditions, no attempt will be made to include other factors having a general bearing on the situation.

The following conclusions were drawn from the NPA Survey, which covered 1950 and the first six months of 1951. While all forms have not been completed, enough have come in to form a reasonably accurate estimate.

INVENTORIES:

Based on actual consumption reported, inventories of diamond bort in the hands of both manufacturers and dealers declined 8% in 1950 and showed a further decline of 9% for the first six months of 1951. The rate of decline for 1951 is, therefore, 18%. Also, the total amount of diamond bort held in all inventories (not including U. S. Stockpile) is less than a six months supply as applied against current usage.

See next page
turn page

III-2

Under "depth of chipping," the 0.0005" represents a D320 grit wheel and the 0.002", a D100 grit wheel. Chipping is the breaking out of tiny particles at the edge where two ground surfaces intersect at an included angle of a little less than 90°. The mating surface is that as ground by a 320 grit diamond wheel.

Chipping is irregular and varies from slightly more than the values quoted to much less. The lower limit of sawtooth pattern (grain marks) can be estimated roughly from the Profilometer readings. Multiply the Profilometer reading (in microinches) by about 5×10^{-6} to get the distance in inches from the bottom of the valleys to the top of the ridges. A Profilometer reading of 2 would then correspond to 0.000010" and a reading of 10 to 0.000050".

3. GRINDING COSTS.

Table 2 presents ranges of costs of cutting off and removing stock. They include some of the lowest costs we have obtained from laboratory grinding with diamond wheels.

Time costs are calculated only for contact time. Handling and other time spent on the job, outside of grinding contact, raises the time cost per unit of work ground in actual practice.

The work ground in all cases was Carboloy cemented carbide. It was 44A grade, except for items 13 and 14 when it was 55A grade.

The operations tabulated should be generally taken as of rough grinding.

One basic figure assumed as common for all items of Table 2 is:

Time cost per hour----------$7.50

APPENDIX III

PERFORMANCE OF DIAMOND WHEEL GRINDING

By H. W. Wagner, Norton Company

1. INTRODUCTION.

The treatment in this report will be to outline the performance of which diamond wheels are capable and will assume that they are available at certain prices, as at present. Also the data will be limited to machining operations which can be and are readily performed by the use of diamond wheels. It is recognized that electro-erosion machining can drill holes and otherwise effect operations in small spaces where a diamond wheel is not applicable.

In the author's opinion, the most significant basis of comparison of competing processes is by means of total cost, per unit of acceptable product. The major elements of total cost are tool cost and time costs. The cost of spoiled work should also be included in the total cost.

Specifications for quality of work fulfilled by diamond wheels and grinding costs resulting from the use of diamond wheels will be given, for machining cemented carbide.

2. QUALITIES OF SURFACES PRODUCED ON CEMENTED CARBIDES.

Table I

Profilometer roughness	2 to 10 (rms.)
Flatness from surface grinding	0.0002"
Depth of chipping of cutting edges of tools	0.0005-0.002"
Cracking of the work surface	None
Burn color left on work surface	None
Pitting of work surface	None

The qualities specified can be reached in commercial grinding without recourse to special equipment or methods. The finest finish (Profilometer 2) of course requires a finer grit than that used for rough grinding. The flatness of 0.0002" requires going over the work with decreasing feeds, after rough grinding.

CONSUMPTION:

Actual reported usage for the first six months of 1951 show an increase over 1950 of approximately 1,500,000 carats, based on a projection covering the entire year, together with a reasonable assumed rate of climb for the last six months.

IMPORTS:

Total imports for 1950 was reported as 5,322,000 carats. Available 1951 figures show bort being imported at the rate of 6,220,000 carats.

RECLAMATION FOR RE-USE:

The amount of diamond bort reclaimed for re-use in diamond grinding wheels and other purposes, together with imports, constitute the total available supply for U. S. industry. The amount of this material reclaimed during the first six months of 1951 shows a substantial increase over 1950. An expansion of this program is now under way, but in all probability the amount of bort reclaimed per year will not materially increase above the present figure.

Summarizing the data presented by the NPA Survey, an alarming picture of dwindling supply is shown. The current usage, as reported, exceeds the present rate of import and reclamation by approximately 500,000 carats for 1951.

It has been thought until recently that added supplies would be forthcoming for 1951 from mine sources, but this has not materialized. It is hoped that an increase of supply will be available during 1952 but this will not be known until after the first of the coming year and in any event will not materially affect the present or future picture as any great increase from mine source cannot be counted on.

It is evident, therefore, that immediate measures must be taken to develop new methods, not utilizing diamond bort, in grinding and forming Tungsten Carbide and other hard metals.

Appendix III-3

Table 2

Grinding Costs, Cemented Carbides

Item No.	Operation	Work Size	Production Per Hour	Costs Per Unit of Work		
				Wheel	Time	Total
1	Cut-off	0.325x0.511"	15.8 sq. in.	$0.42	$0.47	$0.89
2	"	section	16.2	2.96	0.46	3.42
3	"	"	34.2	1.33	0.22	1.55
4	Surface,	9 sq. in.	1.225 cu. in.	2.20	6.10	8.30
5	periphery	surface	4.37	7.87	1.70	9.57
6	Surface,	9 sq. in.	1.20 cu. in.	2.18	6.25	8.43
7	periphery	surface	4.39	8.03	1.71	9.74
8	"	"	4.62	13.65	1.62	15.27
9	Surface,	0.625	0.148 cu. in.	10.98	50.60	61.58
10	side of	sq. in.	0.148	9.30	50.60	59.90
11	cup	surface	.1485	7.79	50.55	58.34
12	wheel	"	.291	25.70	25.80	51.50
13	Centerless	1-1/2-2"	29.4 cu. in.	4.71	.255	4.96
14	Cylindrical	diameter	50.9	26.70	.147	26.85

In Table 2, "periphery" means that grinding was done with the periphery of the wheel. The periphery was used in all cases, except for items 9 to 12.

"Production per hour" is a calculated value. Sometimes the runs were of shorter duration than one hour. For items 9-12, total grinding was for more than one hour each.

The costs are per sq. in. cut in items 1-3 and per cu. in. of material removed in the other items.

The working rim on the side of the cup wheels (items 9-12) was 1/8" wide.

Table 3 gives further information pertaining to the items of Table 2.

Appendix III-4

Table 3

Wheels, etc.

Item No.	Wheel Dimensions	Wheel Structure	Approximate Calculated Price Per Cu. In. of Diamond Portion	Total Work Area Cut or Volume Removed.
1	8x0.055X-"	D60-L100M 1/8	$370	0.306 sq. in.
2	"	D60-L50M 1/8	278	.162 sq. in.
3	"	D100-L100M 1/8	370	.322 sq. in.
4, 5	7x1/2x1-1/4	D100-N100B 1/8	197	0.52-0.55 cu. in.
6-8	7x1/2x1-1/4	D100-L100V 1/8	230	0.52-0.54 cu. in.
9	6x1-1/2x1-1/4	D120-J100B 7/16	215	0.370 cu. in.
10	"	D120-N100B 7/16	215	.3705 cu. in.
11, 12	"	D120-R100B 7/16	215	0.36-0.37 cu. in.
13, 14	20x3x12	D100-N100B 1/16	197	3.6-4.0 cu. in.

Under "wheel dimensions", the first figure is outside diameter, the second is thickness, and the third is hole diameter.

Under "wheel structure", "D" means diamond and the next figure is grit size. After the hyphen, the first letter is the grade, the next figure is concentration of diamond, and the final letter designates kind of bond.

M means metal bond
B means resinoid bond
V means vitrified bond

A higher concentration number means a higher volume per cent of diamond.

The fraction following the bond letter is the depth (in inches) of the diamond portion. A greater depth usually costs less per cu. in.

The price per cu. in. is based on maximum discount and is the net price of wheel divided by the cu. in. of diamond portion on the wheel.

4. ACKNOWLEDGMENT

Those of our staff who have worked up results for this report are B. H. Anderson, C. E. Sweetser, and L. P. Tarasov.

5. DISCUSSION

The comparatively high wheel cost of item 2 is due to the relatively rapid wear on the "50" concentration wheel on this particular operation.

Item 13 in the centerless group shows the lowest total cost per cu. in. of Carboloy removed. This is due mainly to the wide width (3") of wheel face at work. A fast rate of cut is permitted without a high ratio of wheel wear to material removed.

Item 14 represents a faster rate of feed which resulted in much more, and more costly, wheel wear than in item 13.

Costs for items 9-12 are high because of the slow rates of cut encountered in the operation, which made the time costs per cu. in. high.

Internal cylindrical grinding does not happen to be included in the tables. It and other operations done with ordinary grinding wheels can also be done with diamond wheels. In practice, diamond wheels are generally not made in such large sizes as are those of aluminum oxide and silicon carbide. Diamond wheels are employed mostly for grinding hard non-ductile materials such as cemented carbides, natural stone and glass and other ceramics.

APPENDIX IV

THE FORMING OF GAS TURBINE ENGINE BLADE FASTENINGS

By John C. Redmond, Kennametal, Inc.

The rotating blades or buckets of gas turbine aircraft engines are now generally held in the turbine disc by a mechanical fastening. This fastening takes different forms such as the series of serrations referred to as the pine tree or a roll and many other forms. These must be made quite accurately both with regard to form and dimensional tolerances to fit the mating slots which are broached in the turbine disc.

The alloys of which such turbine blades are now generally made are sufficiently hard to machine that it is necessary to grind the fastening form by some such means as crush from grinding using aluminum oxide wheels. However, the quantities of blades which are required are mounting rapidly and in the event of a real emergency we have been told they would increase many fold. Hence, the new process methods may well have a place in the forming of roots on alloy blades.

There is another phase of turbine blade development which is even more important as far as new processes for machining and grinding methods are concerned. This is in the work under way to develop less strategic metal ceramic materials to replace the presently used alloys. In particular, much work which is showing promise is now under way on cemented titanium carbide. Since this is a new field, no method for forming of roots in quantity production is as yet established. Crush form grinding, if applicable, will be more difficult than for the alloys because of the greater hardness of the carbide compared to the alloys. The problem will be somewhat simplified by the rough forming of the root. Diamond form grinding, which is being used for producing experimental root forms, is certainly not applicable because it is too slow and too expensive for such an application in production. The number of

blades which will be required is in the hundreds of thousands per month. This will require a forming time per root of a very few minutes.

Two representative root forms are shown. It will be observed that dimensional tolerances are a few thousandths, overall tolerances $\pm$ .001 ins. Angular tolerances are a few minutes.

This problem should present a fertile field for new processes for machining and grinding.

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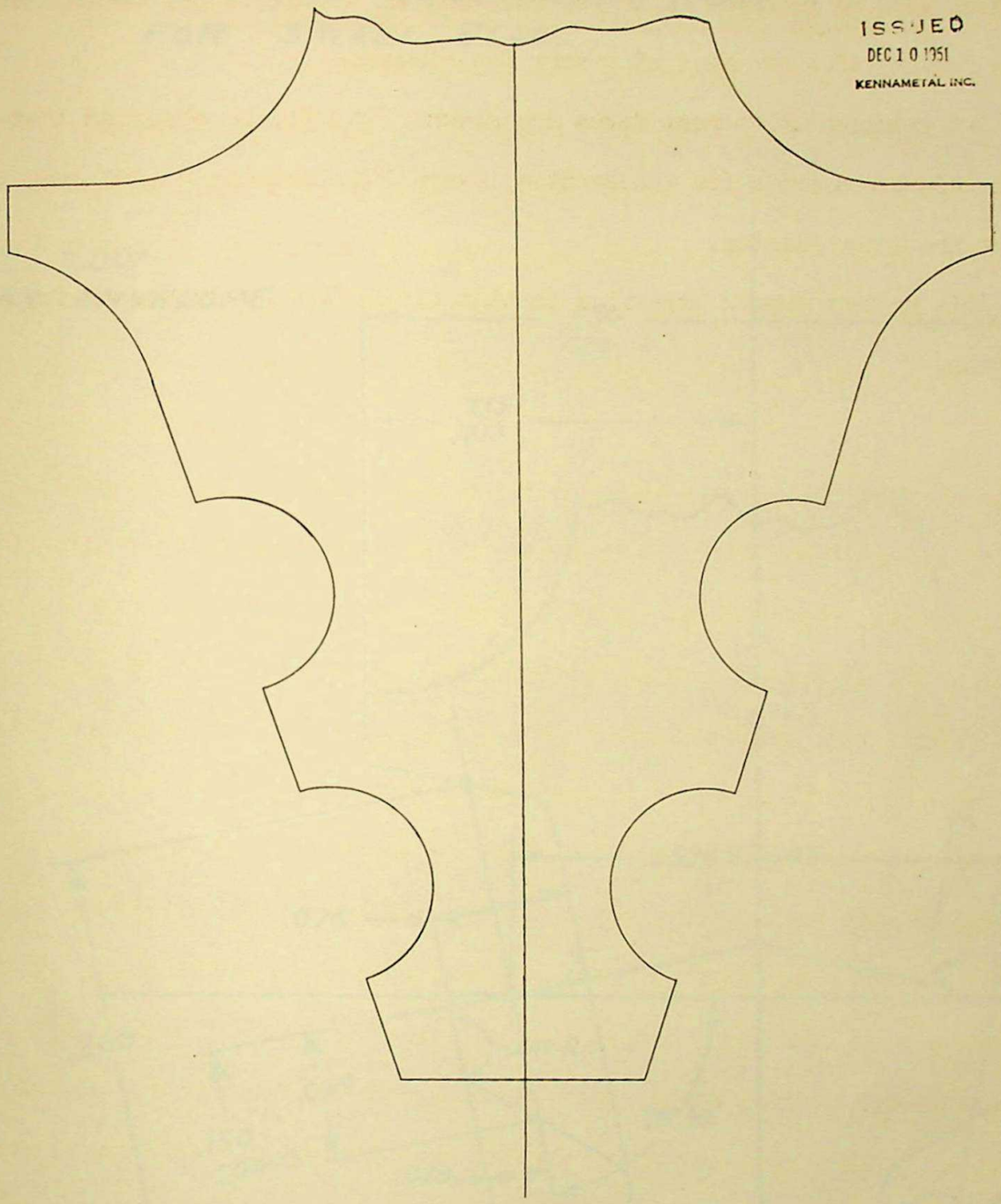
KENNAMETAL INC.

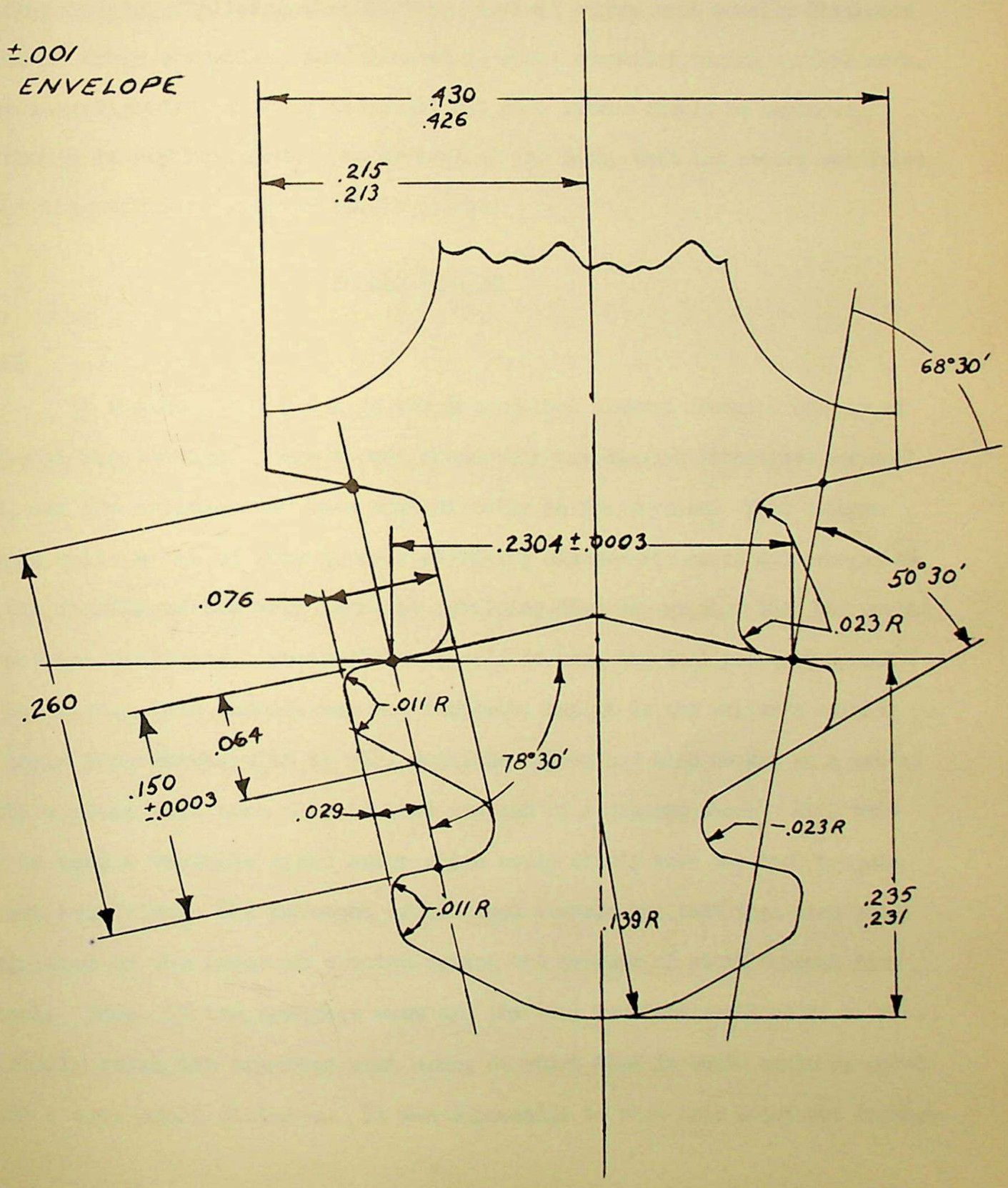


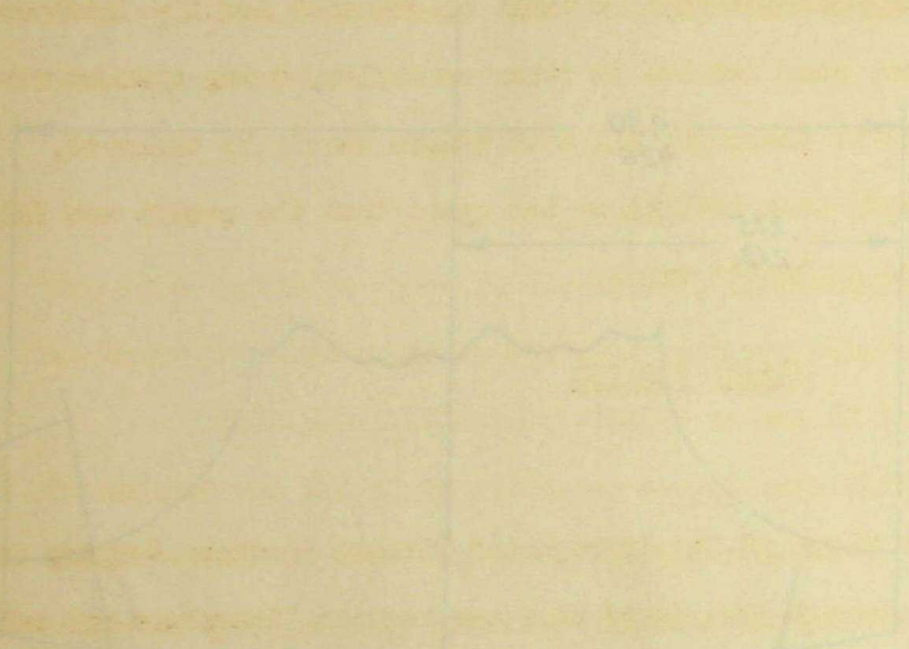
5 X SIZE

REPRESENTATIVE MULTI PIN ROOT
FOR LARGE BLADE

10 X SIZE
REPRESENTATIVE MULTI LAND ROOT
FOR SMALL BLADE

..ERANCE ±.001
OM MEAN ENVELOPE





APPENDIX V

EUROPEAN ACTIVITIES ON ELECTRO-PROCESSES FOR MACHINING AND GRINDING

by

L. H. Metzger,
Super-Cut, Inc.

A great many people in Europe know about and have experimented with carbide grinding, utilizing electricity. A visit to one spot usually discloses reports of other companies, some located in other countries, doing similar work. If the investigation is to be thorough, all such rumors should be explored, even though it may be found, upon arrival at the spot, that the report was false or that the experience was of little value.

PLANTS VISITED

England

In England, the plant of the Impregnated Diamond Products Company at Gloucester was visited. Here it was found that the Russian literature was well known, and the articles had been read directly in the Russian. This concern had done quite a bit of work towards utilizing electro-processes and recognized that the spacing of the work from the revolving disc was vital. They had worked on a machine utilizing a photo-electric cell to keep the tool properly spaced from the disc. This machine was not complete, but it is the writer's opinion that their experiments with it will continue. They had also worked on a set-up whereby a plain cast iron disc is used instead of a diamond wheel. With this would be used a variable speed motor which would slowly move the tool towards the cast iron disc. The movement of the tool towards the cast iron disc would be regulated by the amperage created during the process of stock removal from the tool. Thus, if the amperage went up, the tool would be stationery, or move very slowly until the amperage went down, at which time it would again be moved forward a very small distance. It was impossible to show this setup but further

technical information regarding it was promised.

In connection with this, it would seem to the writer that while this might be practical if only one size tool were being ground, it would present certain problems where the contact area of the tool would vary in size constantly from one tool to another. In addition, this concern had experimented with the ideas presented in:

D. T. VASIL'EV[4,6]

B. R. Lazarenko[7,8]

The above articles describe electronic, electromagnetic and solenoid arrangements to bring the work close to and away from the revolving disc.

IMPREGNATED DIAMOND PRODUCTS is one of the leading diamond wheel makers in England and makes, in addition, the Wickman Carbide Tool Grinder. It is the writer's opinion that they will shortly present to the English market a complete setup for successfully grinding tungsten carbide by some electro-process.

Holland

HERMES METAALWAREN FABRIEKEN, Amsterdam. A visit to the above plant revealed information given was incorrect. These people had never used electro-processes to grind tungsten carbide.

N. V. WALLRAMIT HARDMETAAL MY. near Rotterdam. Investigation revealed that whereaw these people were familiar with the Russian art, they had just begun to give it consideration and have not progressed sufficiently to warrant a detailed report.

PHILLIPS CO. of Eindhoven. While in England, the writer met a top executive of this company who said that Phillips had progressed considerably in

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4, 6, 7, 8 - See Bibliography

electrolytic grinding and that they had used diamond wheels and an electrolytic fluid for such grinding.

Germany

VIDIA KRUPP at Essen. This division of the Krupp Works, making tungsten carbide, experimented with the Russian ideas as far back as 1946 and 1947. Their activities fell in two groups. One with utilization of a diamond wheel and possibly wheels containing other non-conducting abrasives, the other utilizing plain metal discs with no abrasives. The only file that "could be found" gave data only on the latter and not the first activity and therefore it was necessary to reconstruct by memory what had been done. In the utilization of a diamond wheel, there was used D.C. current employing between 15-20 volts and 30-40 amperes. The RPM of the wheel could not be remembered. The electrolytic fluid used consisted of 10% caustic soda and 90% water, as well as a standard type of "water glass" or high ratio silicate of soda solution (approximately 3.25 parts of silica dioxide (SiO_2) to one part sodium oxide (Na_2O)).

The writer was told that the results obtained while grinding, using electricity with no pressure on the tool gave approximately the same speed of metal removal as when not using electricity in normal diamond grinding. When pressure was applied with electric current the speed of metal removal increased approximately 300%. However, this experiment stopped after they concluded that the edge or corner of the tool being ground seemed always to be rounded instead of a nice, sharp, square corner, which they prefer. Also they were not satisfied with the finish obtained.

Considerably more work was done in their second line of endeavor. This was done in conjunction with a Mr. Norbert Eberle of St. Gallen, Switzerland, about whom more will be said later in this report. Here, two types of experiments

were conducted, one using direct current of from 15-20 volts, 30-40 amps, and the other using alternating current up to 100 volts and permitting the amperage to develop volume according to the square inch area of contact. In both experiments, they again tried the same chemicals as mentioned above, namely, 10% caustic soda and 90% water, and a high ratio silicate of soda solution (approximately 3.25 parts of silica dioxide [SiO_2] to one part sodium oxide [Na_2O]). Experiments were conducted using first 1750 RPM as well as 3500 RPM. Some of their first tests involved using a brass disc 350 mm (13.8" diameter) and very thick. They then tried using a thin brass disc, 1½ mm (.059") as a cut-off disc. It was found that whenever such a brass disc was used, the brass diffused into the contact surface of the tungsten carbide tool a distance of from .02 mm (.00079") to .06 mm. (.0024") Subsequent tests proved this caused a softening of the cutting edges of the tools and shortening the life thereof. They also found microscopic cracks in the tools which had not been there before. Subsequent experiments were conducted using a chromium steel type of disc but otherwise the same setups. These experiments produced no diffusion into the tungsten carbide but they still produced microscopic cracks in the finish, both on the face as well as the edges of the tool and this was not acceptable.

Accordingly, Krupp had done nothing along these lines in several years but advised that Mr. Eberle was continuing to experiment and was producing machines for this purpose.

NOXAS UNION COMPANY was visited at Frankfort, Germany. Here it was learned that the Eberle machine which the Krupp Works had mentioned was actually being made in conjunction with the efforts of Mr. Eberle. This machine was seen and attached hereto is a picture of it.

The method used by this machine employs no fluid at all. There is used alternating current up to 100 volt; the amperage developed is directly related to

the square inch area of contact of the tool against the wheel. The wheel is approximately 12" diameter with a thickness of 1¼. On each side outer face of the wheel, as well as across the periphery of the wheel, there have been machined multiple small grooves, about 1/32" wide, 1/16" deep, spaced about 3/32" apart, giving the effect of a corduroy surface. On the side faces, these grooves run radially. On the periphery, the grooves run parallel to the shaft rotating the wheel. It was explained that the purpose of the grooves was to cause just enough minute vibration to provide the spacing necessary or breaking of the current, and that this would happen even though the tool was held firmly in the fixture shown in the picture. Since no fluid of any kind is used, there is produced when grinding, what looks like a large arc extending down from the tool to about 1½". This arc is sometimes blue and sometimes yellow. Because it was found that the metal of the disc or wheel diffuses into the metal of the tool being ground, it has been the practice of the maker to spray that portion of the disc or wheel that comes in contact with the tool, with a metal, composition of which is the same as the tool being ground. The exact technique of cold spraying the wheel was not given and was the only information withheld.

While this is much slower in grinding than electrolytic methods seen in the States, nevertheless it did seem to put a semi-polish on the corner or edge of the tool being ground. After seeing this, the writer concluded that it was far too slow for usage in America, where grinding in production is much faster than this machine can provide, although it may have certain limited applications.

REPORTS OF OTHER ACTIVITIES

Questions were asked at all places visited regarding such grinding in Europe. The following is the information as summarized from the various reports given.

Germany

It was reported that Walter Tubingun, Baizy, were grinding tungsten carbide electrolytically as was the firm of Folkswagon, Braunschweig, Germany.

Belgium

No specific names of firms doing this in Belgium were given. On two occasions it was reported that in the last several years great progress has been made in Belgium in the grinding of tungsten carbide and that probably such developments would be found on investigation starting at Brussels. It is reported that the Syndicate in Belgium, owning diamond properties in the Congo, have started their own diamond wheel manufacture in Brussels and are interested in tungsten carbide plants in Belgium and the probability is that the latter will have done some work along the lines covered by this report.

France

While no definite company using electricity to grind carbide in France was reported, many reports indicated that the French likewise are on their toes as regards recent developments and a thorough investigation probably would reveal considerable activity.

Switzerland

Answers to queries generally point to more progress having been made in Switzerland, utilizing electricity for grinding carbide, than any other country in Europe and the following two names were given:

Voegeli and Wirtz, Bien, Switzerland
Anthony Vogels & Son, Ltd., Pieterlen, Switzerland

In addition, Swiss Patent 257468 has been issued to Lazarenko, April 1949, which patent covers the grinding or machining of metals using electricity and a fluid (a translation has been made by the writer).

Obviously, there is considerable activity along these lines in Switzerland, although no outstanding or startling results were reported.

England

Time prevented further investigation in England but it was reported that Wickman, who makes diamond wheels, is exhibiting in Nov. 1951 a "Method X" machine and they will shortly be operating under a license from Firth Sterling for this machine in England. It was also reported that work had been done by the G. E. Carbide Plant in England, as well as the Murex Company, who make tungsten carbide. The type of work the latter two have done was not known definitely by the person reporting it but he felt that it was more or less along the lines of the process used by "Method X" and "Elox".

In England, British Patent 637872 covering electro-process was issued in May 1950 to Rudorff.

Italy

It was reported the Russian ideas had been experimented with in Italy but the person reporting it did not know the names of the firms who had so experimented.

CONCLUSIONS

It seems to the writer that certain definite conclusions can be reached, namely:

(1) that technicians in Europe know of the possibilities of grinding tungsten carbide, utilizing electricity as well as do the Russians and ourselves in America, and have read the literature.

(2) they have been, and will continue, to experiment towards perfecting better methods along these lines, regardless of their progress up to date.

(3) generally speaking, they have not reached as satisfactory a degree of accomplishment to date as we have in America.

ACKNOWLEDGMENTS

In closing, the writer wishes to express sincere appreciation for the cooperation given by Dr. Amos Shaler, Chief Metallurgist Engineer under Dr. Bell in the Division of Naval Research, U. S. Embassy, London, who so courteously and efficiently arranged for U. S. representatives as well as British representatives to give assistance at the various points visited. He would also like to express his thanks to Lt. Cdr. Fox in Naval Research in our Embassy at the Hague and Dr. R. M. Langer in Naval Research at our Embassy in Koblenz, as well as Dr. Frances of the British Embassy in Dusseldorf.

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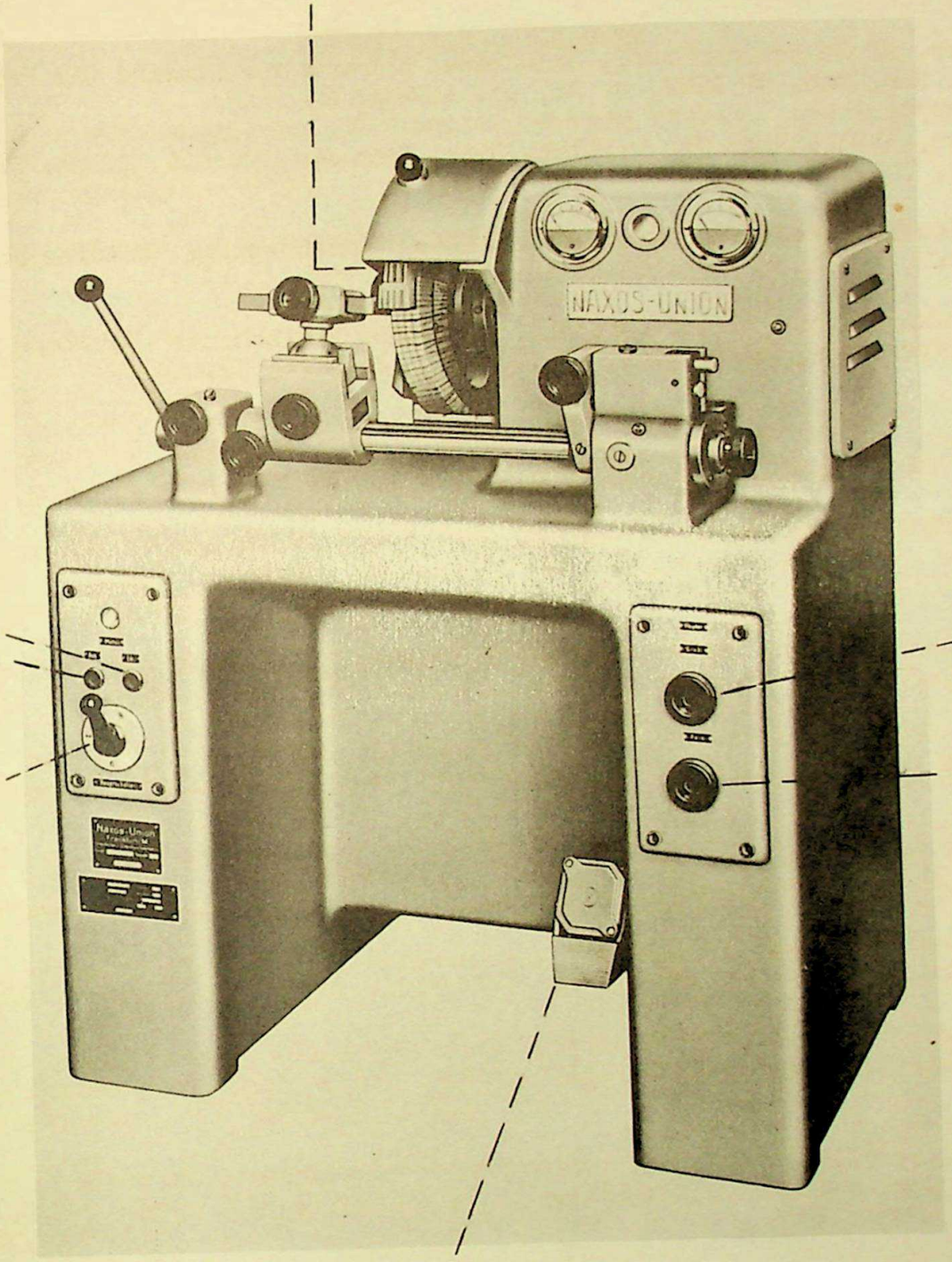
Corduroy Surfaces
NAXOS-UNION
Coarse V and
Amp Regulator
Fine V and
Amp Regulator
Foot Switch
to Turn
Current on

APPENDIX VI

THE ELECTROLYTIC PROCESS FOR SHAPING METALS AND METAL CARBIDES

by
George Keeleric, United Drill and Tool Corp.,
Howard T. Francis, Armour Research Foundation, and
Charles L. Faust, Battelle Memorial Institute

HISTORICAL BACKGROUND

The electrolytic process for shaping metals in its original form, proposed by Gusev (USSR), concerns a method whereby metal is removed from a workpiece by what the Russians call electro-errosive action. In Gusev's method as described by Skornykov (1), Popilov (2), and Noskov (3) (USSR), a cathode consisting of a revolving metal disc slides against an anodic workpiece while an "electrolyte" is applied to the disc and workpiece in the same manner as a coolant is applied to a grinding wheel and work. The "electrolyte", according to Popilov, consists of technical water glass of suspensions of clays in .1 to .2% NaCH solutions.

The pressure applied to the workpiece against the revolving disc may, according to Noskov, vary from 0 to 1 Kg/cm^2, with optimum stock removals obtained at 0.6 kg/cm^2. The speed of the disc is recommended by Noskov to be from 8 to 12 m/sec. The voltage applied between disc and work is from 8 to 30 volt, with cutting rate proportionate, and the quality of finish is inversely proportional to the voltage applied. Gusev has, according to Noskov, explained: ".....that the removal of metal proceeds both by electrochemical and mechanical action on the anode. The passage of direct current through the special electrolyte causes the formation of a film of insoluble compounds on the anode, protecting it from further electrolytic action. Removal of this protective film from the

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(1) Promyshlennaya Energetike 3, 1 (1946), 11.
(2) Zavodskaya Laboratoriya 14, 3 (1948), 358-361.
(3) Stanki I Instrument 19, 10 (1948), 20-22

surface of the anode by the rotating wheel forming the cathode exposes a fresh surface of metal to the action of the electrolyte and thus assures the continuous removal of metal from the anode...."

All the Russian authors mentioned above refer to the presence of sparking and/or arcing between cathode and anode, but also emphasize the need for keeping sparks and arcs at a minimum in order to minimize wear of the cathode. Lazarenko (4) refers to suggestions for electrolytes by K. K. Khrenov, who recommends solutions of sodium salts of nitric, hydrochloric, boric, silicic, and phosphoric acids as having arc-extinguishing properties.

RECENT EXPERIMENTS

On the basis of experiments with the method described by Popilov (2) carried out in the laboratory of United Drill and Tool Corporation, it is reasonable to assume that Popilov metal removal is mainly carried out by means of the sparks and arcs generated in the intermittent contact area between the disc and workpiece.

In the first of these experiments, the disc consisted of a metal bonded single layer diamond wheel according to Keeleric (5), which was used as a cathode. In this wheel, diamond particles protrude an even distance above the metal bond. As diamonds are abrasion resistant and electrical non-conductors, they are ideally suited as spacers between the cathode and the anode, and furthermore, they will provide that wiping action of the anode compounds discussed by Noskov.

It was thus found that when employing the electrolytes (water glass) according to Popilov and providing sufficient spacing (25 microns) to avoid arcing and sparking, only the insignificant current of a few amperes passed between anode

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(4) Stanki I Instrument 17, 12 (1947), 8-11
(5) U. S. Patent No. 2, 368,473

and cathode. (15-25 volts; anode area 0.74 cm^2). Considering the low conductance of the water glass solution, this is not surprising.

A number of other solutions of high conductivity, such as neutral salts of hydrochloric, sulfuric, and nitric acid, were tried. These solutions resulted in highly increased currents - for example, 150 amperes at 16 volts with an anode of hardened high speed tool steel of 0.8 cm^2 anode area (current density 18,400 amp/dm^2).

Experiments with sintered tungsten carbide pieces of the same dimension showed somewhat less current densities, as maximum current obtained under the same conditions did not amount to more than 4,000-9,000 amp/dm^2.

Besides high speed steel, ordinary steels, copper, aluminum, titanium, and alloys thereof were tried, and it was found that all of these could be shaped electrolytically with higher current densities than those obtained with sintered carbides.

In order to determine the most suitable spacing distance between cathode and anode, a series of experiments, as described below, were carried out.

The cathode consisted of a cup-shaped cast iron disc A (See Fig. 1). The anode consisted of 0.5 cm diameter rod B, held in holder C. The cathode and holder were rigidly suspended from a beam D, which by means of needle point bearings could turn vertically at E. From the other end of the beam a plunger F was suspended in such a way that it could freely move in fixed solenoid G. The positive lead from a rectifier was connected to one end of the solenoid; the other end, through a mercury cup H, to the beam and C, the anode holder. The negative pole of the rectifier was connected to the cathode wheel through the brush and ring I. A weight K moves the adjustment of the cathode pressure against the anode.

By means of a switch L the solenoid might be by-passed. By means of a nozzle M, reservoir N, and pump O, an electrolyte was carried to the anode-cathode space. Ammeter P measures the constant direct current in the circuit. Ammeter Q, consisting of an A.C.-meter with a torroidal current transformer, measures any pulsating current which might be generated by sparks or arcs.

The current passing through the solenoid exerts a pull on the plunger, thereby increasing the distance between anode and cathode. By adjusting the position of the weight K, it was possible to keep a constant space between the wheel and the workpiece, as the weight would automatically feed in the work until the current reached a certain value, at which point the pull of the plunger would balance the force of the weight. This simple arrangement, unfortunately, would only work automatically when the area of the tool facing the wheel was constant, or in other words, when the current through the solenoid was substantially constant. In practical grinding, the area of the workpiece contacting the wheel, except for cylindrical grinding, is of course seldom constant.

With this electromagnetic automatic feed arrangement, it was found that high speed steels, cobalt, copper, aluminum, and titanium and its alloys could be shaped at high current densities without scraping or wiping off the anode film as demanded by Gusev's theory. A brown film was formed on steels, especially when the electrolyte was neutral or slightly alkaline, but this film seems not in any way to interfere with the speed of stock removal.

However, electrolytic "grinding" of sintered tungsten carbides could not be carried out with any of the electrolytes tested, without providing the wiping action of Gusev, by means of a metal bonded abrasive wheel, the abrasive acting as wipers (-and spacers).

The following experiment might throw some light on this problem. A piece of tungsten carbide was made an anode at the anode current density of 1 amp/dm^2 in four solutions. (1) 10% HCl, (2) 10% H_2SO_4, (3) 10% HNO_3 and (4) 40 g/l $NaNO_3$-20 g/l $NaC_2H_3O_2$ (pH 5.6). In all cases a heavy, adherent coating of apparently WO_3 was formed on the specimen. The color of the electrolytes indicated that the cobalt binder of the tungsten carbide particles formed salts of the acids employed.

The specimen in the sodium nitrate-sodium acetate electrolyte lost 0.87 grams in weight after 1 amp/hr., i.e. after the oxide (s) was mechanically removed from the specimen.

The current space-distance relationship was determined as follows. A double slit formica tube (Fig. 2) was pressed over the specimen, the slits providing passage for the electrolyte. Initially, the slitted part of the tube would protrude 2.5 mm over the edge of the specimen. The switch L was closed so as to short-circuit the solenoid. As grinding proceeded the cast iron disc would wear the formica and wear it faster than the specimen was ground, thereby decreasing the gap between the specimen and the disc. At intervals the current was noted and the protusion of the formica above the ground surface of the specimen was measured on a shadowgraph. The test was continued until sparks or arcs were generated and registered on the ammeter Q. Graphs obtained by plotting current against gap distance at different voltages and surface speeds are attached as Figs. 3 and 4.

PRESENT STATUS OF ELECTROLYTIC GRINDING

A tentative and qualitative description of the phenomena associated with electrolytic grinding is as follows: The approximate rate of metal removal which has been achieved with high-speed steel is about 4 mm/min. The current density

required for such a removal rate is about 13,400 amp/dm^2. The coulombic efficiency of the process is in the vicinity of 90 per cent. The voltage required for the attainment of the above cutting rate is in the range of 25-35 volts. The electrode spacing corresponding to the conditions described is about 20 microns.

Judging by the conditions described above, it appears that the very thin film between the workpiece and the cathode wheel is swept past the mating surfaces at sufficiently high velocity to prevent severe polarization of the electrodes. Such sweeping action also prevents generation of excessive temperatures in the electrolyte, since it is continuously being replaced by fresh solution at the average temperature of the bath. Several bits of evidence, however, point to the fact that a very definite polarization film exists immediately adjacent to the anode surface. This film seems to be extremely thin, and uniformly distributed on the anode surface, since the quality of finish obtained in electrolytic grinding is exceptionally good as a general rule. One typical sample, checked on a brush analyzer, showed 5 micro-inch r.m.s. Still another fact points to the existence of a thin polarization film at the anode: iron and other metals can be satisfactorily "electro-machined" even when a neutral or slightly alkaline solution is used. This points to the existence of an acidic film immediately adjacent to the anode, caused by the polarization resulting from the extremely high current density employed.

From the results thus far obtained, electrolytic grinding appears applicable to any metal or alloy, provided only that the metal can be anodically dissolved at high rate. In tests made heretofore, tungsten carbide dissolved slower than metals. The background data encourage further study with tungsten carbide and other carbides. Present knowledge shows the direction such a study should take: (1) discovery of an electrolytic solution in which tungsten carbide

(or other selected carbide) is convertible to "dislodgeable" products at very high anodic current density; and (2) provision of anodic conditions that set up the minimum polarization.

For work under (1) development of solutions of anodically very active anions, which also form very soluble tungsten or metal salts, would be highly desirable. Solubility is preferred to insoluble salt or insoluble oxide formation and removal of such by mechanical means during anodic dissolution.

Electrical and mechanical assistance is an added necessity on (2) to speed up the metal dissolution rate. One or both types of assistance can reduce the anodic polarization even of the most active electrolyte. Alternating current could be superior to direct current, because of lowering polarization, providing attack of the disc can be prevented. This is evident in the high rate that high current density a-c causes iron to dissolve in sodium cyanide solution, whereas d-c causes complete passivity. A cathode surface, provided with nonconducting spacers, will provide a wiping action that reduces polarizing "films and removes loosened carbide particles or oxides of metals. The diamond-impregnated wheel mentioned previously is an example of the latter situation. Rotation of the cathode wheel and solution flow are needed to supply rapid agitation for removal of anodic products and renewal of solution in the cutting zone.

General experience in anodic dissolution of metals gained in electropolishing, electrodeburring, and electromachining is quite extensive, and can supply the details needed in a study to devise a method or methods for electrolytic grinding of carbides.

CONCLUSIONS AND RECOMMENDATIONS

Electrolytic grinding is an electrochemically sound procedure having very promising characteristics. The fact that fairly rapid metal removal can be achieved without the use of hard cutting materials and, in fact, without any wear at all on the cathode wheel surface, makes the method particularly attractive. Contoured wheels, for example, could be used for refinishing machine tools with a very minimum of redressing of the grinding wheel.

Electrolytic grinding will always be limited to the electrolyte in which a selected metal or alloy is anodically active. Electrolytic grinding requires that the electrolyte maintain very high anode current densities, and that rapid agitation should be provided to minimize polarization.

Electrolytic grinding should not consume the properly designed cathode disc. Although current densities will be high, the actual amperage will be in the realm of practical transmission limits and voltages are likely to be low enough to be without hazard to operators.

Technically, a process for electrolytic grinding of carbides and hard alloys appears attainable by further research development. Achievment of ultimate efficiency will depend on discovering an electrolyte (or electrolytes) as discussed herein. This is a problem for which electrochemical background is excellent.

Practically, a successful process depends on developing suitable electrical or mechanical control devices for spacing the cathode disc and for solution flow in the zone of electrolytic cutting.

Commercially, electrolytic grinding is simply another method for tool or surface shaping. Its use must stand on relative economics, special applicability or results, or relief of materials in short supply.

Appendix VI-9

Recommendations

(1) Review the industrial need for a new process for shaping carbides (or hard alloys).

(2) If a need is found, the performance specifications that must be met by any new process should be cited.

(3) If a need is found, the electrolytic grinding prospects should be reviewed as to whether its potentialities are diminished because of the findings in (2), and if not, a research and development program should be considered for devising electrolytes and machines for electrolytic grinding, and the convertibility of presently used machinery to electrolytic grinding.

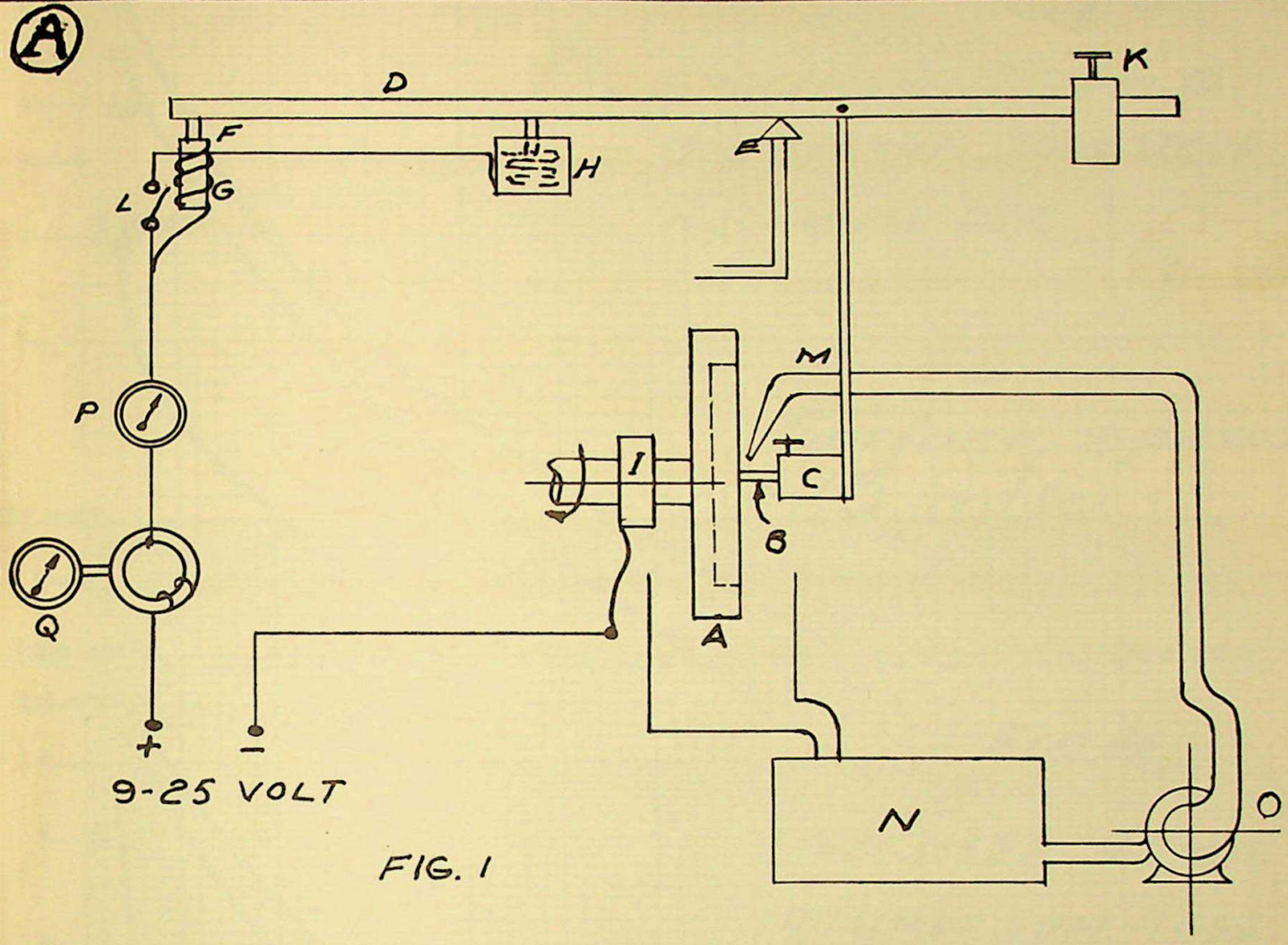


FIG. 1

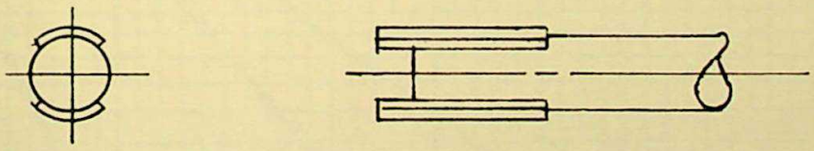
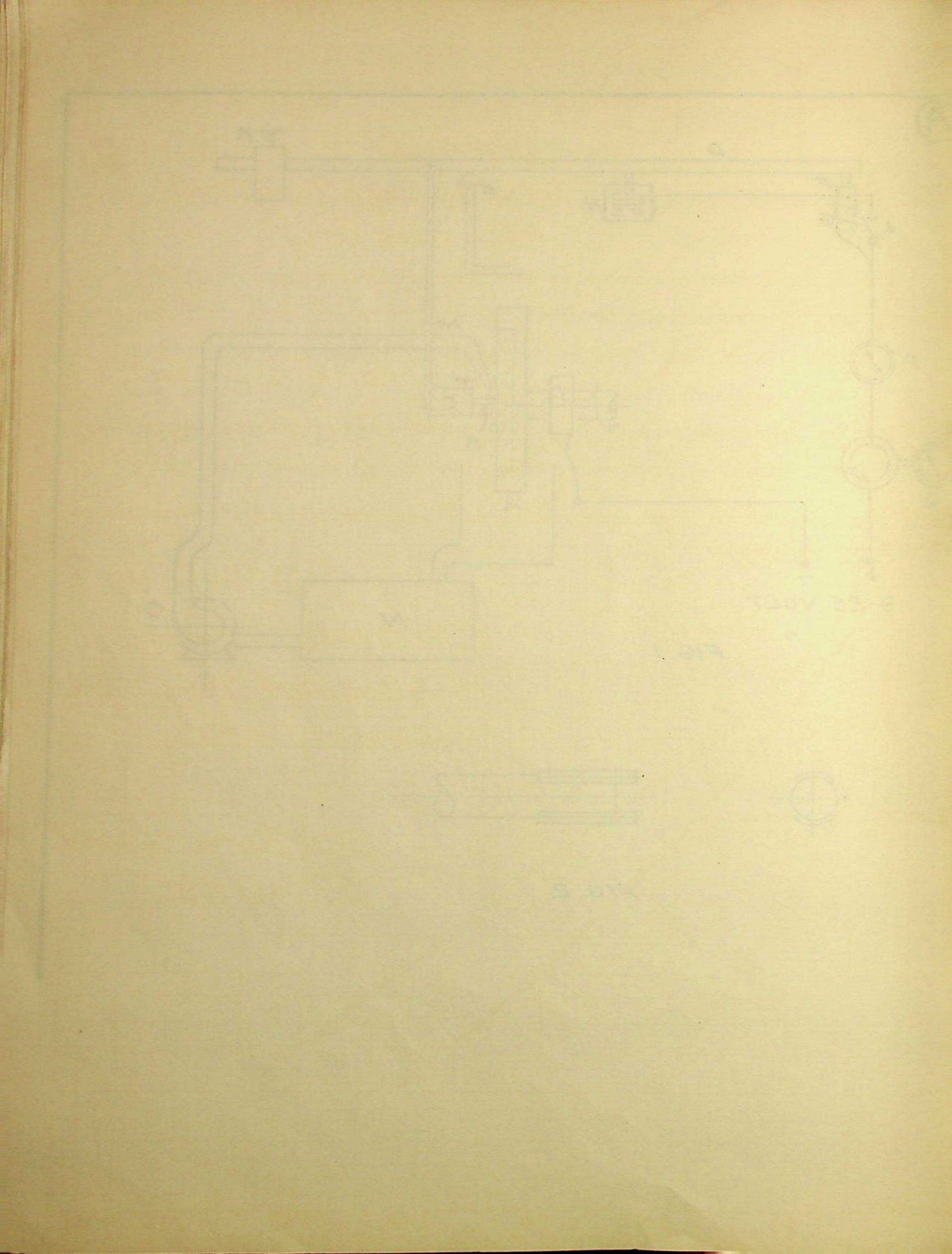
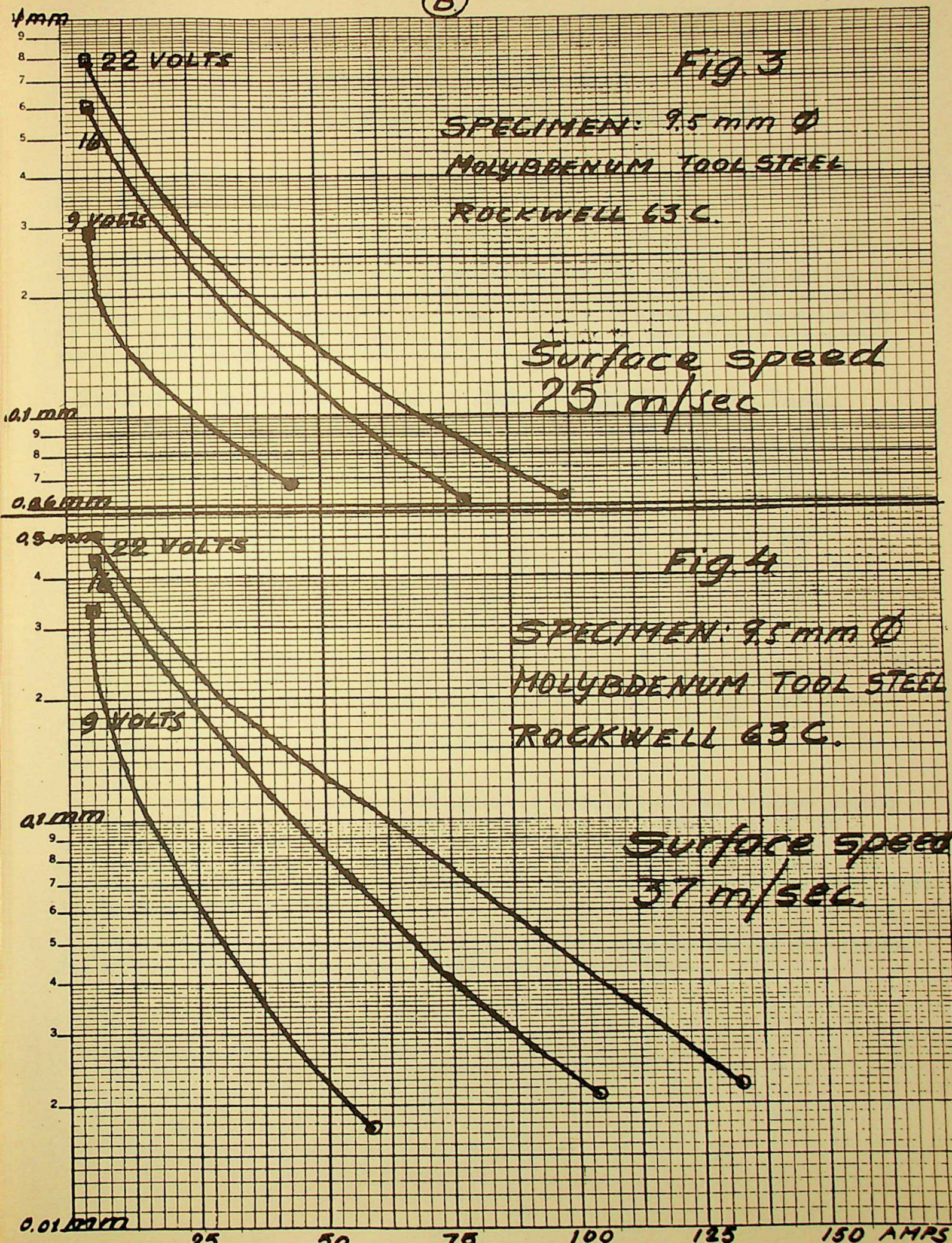


FIG. 2




1 mm
9
8
7
6
5
4
3
2
22 VOLTS
16
9 VOLTS
0.1 mm
9
8
7
0.06 mm
Fig. 3
SPECIMEN: 9.5 mm Ø
MOLYBDENUM TOOL STEEL
ROCKWELL 63 C.
Surface speed
25 m/sec
0.5 mm
4
3
2
22 VOLTS
16
9 VOLTS
0.1 mm
9
8
7
6
5
4
3
2
0.01 mm
Fig. 4
SPECIMEN: 9.5 mm Ø
MOLYBDENUM TOOL STEEL
ROCKWELL 63 C.
Surface speed
37 m/sec.
25
50
75
100
125
150 AMPS

Supplement to the Report on the

ELECTROLYTIC PROCESS FOR SHAPING METALS AND METAL CARBIDES

Concerns rate of stock removal of tungsten carbide by means of electrolytic grinding.

Carboloy grade 999 and 883 respectively, in form of 3/8 inch diameter cylindrical rods were fed perpendicular into a cup shaped cathode wheel at different voltages and amperages. A spacing between the cathode wheel and the carboloy was obtained by 90-100 mesh diamond particles embedded in the cathode surface, the diamonds protruding less than 1/1,000 inch above the cathode surface. No more pressure than that necessary to keep the work in contact with the diamond particles was employed. The following figures were obtained:

Specimen	Carboloy #	Volts	Amps.	Grams/Min.	Cu. In./Hr.
A_2	999	0	0	0.04	0.00775
B_1	999	5	16	0.3	0.0725
B_2	999	10	24	0.24	0.058
A_1	999	15	36-38	0.36	0.0865
C_2	883	0	0	0.02	0.0049
C_1	883	5	16	0.2	0.049
D_1	883	10	24	0.26	0.036
D_2	883	15	36-38	0.4	0.098
G	883	15	36-38	0.44	0.108

The pH of the sodium nitrate solution varied from speciman A 1 to G from 7 - 8. Each sample was run at least 5 minutes. With the protrusion of the diamonds employed (spacing) during this experiment, higher voltages than 15 would result in sparks being generated between the cathode wheel and the carboloy specimens. The maximum current density obtained under these specific conditions was 345 amp/sq. in.

With smaller anode contact areas (of carboloy) a higher current density is obtainable (but a smaller absolute amperage) due to increase flow of the electrolytes. Conversely, at larger anode areas higher amperages are obtained but the current density will be slightly lower up to an area of one square inch at which point the efficiency falls off due to faster dissipation of the electrolyte in the anode-cathode area.

The finishes obtained were below 15 microinches RMS for all the samples. The surface finish is independent of the rate of stock removal.

APPENDIX VII

ELECTRO-SPARKING PROCESS FOR SHAPING CARBIDES

By Ian McKechnie, Chrysler Central Engineering, and
D. F. Dickey, Firth Sterling Steel and Carbide Corp.

We believe that the application of the electro-sparking machining technique to the shaping of tungsten carbide is a well established and practical process.

The forming of internal shapes is currently being performed commercially, while external shapes, difficult to form by normal grinding techniques, are also being formed by this method.

Most effort to date has been directed to the formation of shapes difficult or impossible to attain by conventional processes and for this reason, the direct substitution of this process for conventional machining methods is somewhat difficult to evaluate.

As in most machining processes, accuracy and cutting rates are inter-related factors. Accuracies of .0002 inches or less at low cutting rates are obtained, while the accuracy of repetitive operations is even greater. Material removal rates in the formation of internal apertures which leave a surface finish of approximately 50 micro inch rms will currently run about .003 to .004 cubic inches per minute; however, removal rates do not necessarily reflect total volume removed, trepanning normally being used for large cuts. It should be emphasized that these cutting rates apply to machining tungsten carbides, since the composition of the materials being cut is a determining factor in the removal rate.

The use of present commercial equipment results in economies when applied to the removal of material from apertures which cannot be generated by rotation or in which appreciable thickness of cut is required.

To date very little effort has been directed toward the application of this process to the sharpening of tungsten carbide tools, but preliminary investigations and the Russian development reports indicate the practicability of the application. Even though cutting rates on external surfaces exceed the figures given above for internal apertures, the economic value of sharpening tungsten carbide tools by this method is unknown at this time.

While the sharpening of tungsten carbide tools by the diamond grinding process tends to generate minute thermal cracking of the cutting edge, which probably adversely affects tool life, it is believed that sharpening properly done by the electro-sparking method does not have this effect, although it is possible to produce cracks by improper operation.

There are at least two companies actively engaged in research and development programs directed toward the improvement and diversification of electro-sparking techniques. While it is expected that the projected rate of research will, within one year, result in machines which will cut many times faster, this program can be accelerated by supplying those presently engaged in research with effective directives for equipment, machine tools, and capital.

APPENDIX VIII

ULTRASONIC GRINDING AND MACHINING OF BOTH METALS AND NON-METALS

By Arthur Kuris, Cavitron Equipment Company

This is a summary report on the ultrasonic process for grinding and machining both metals and non-metals.

For over six years ultrasonic mechanical vibrations have been used to grind, machine, bore, and thread hard and brittle materials. This process is being applied on a rapidly increasing scale to commercial operations involving the cutting and machining of tungsten and titanium carbides, ferrites, sintered aluminum oxide, etc.

Ultrasonic processing is of particular importance in view of the diamond shortage because:

1. The process is best carried out with inexpensive boron carbide as an abrasive.

2. The process cuts all materials (both metals and non-metals) which are ordinarily ground and machined with diamond and is the only process that will cut all hard materials that diamond will cut.

3. The process will cut an opening or recess of any shape or contour in carbides, ferrites, sintered aluminum oxide, etc., including the forming of internal threads and the making of complex extrusion dies, minting dies, stamping dies, embossing dies, etc.

APR 24 1952
U.S. PATENT OFFICE

THE PROCESS:

In the ultrasonic process a tool is formed having an end of the shape of the desired hole, cavity, or contour which it is desired to cut. This tool is connected to a device which will cause the tool end to oscillate at very high frequency though low amplitude. The tool end is pressed against a workpiece and a mixture of finely divided abrasive (boron carbide) and water is flowed around and under the end of the tool on the face of the workpiece.

Ordinarily no movement of the tool is visible to the naked eye as the amplitude of movement of the tool at the high frequencies employed is very small.

Even though no movement of the tool end is visible, the tool, under light but continuous pressure, sinks into the workpiece (which may be a carbide or a ceramic body such as aluminum oxide or a ferrite) and a hole, aperture, or contour is formed in the shape or cross-section corresponding directly to the shape of the tool end.

THE EQUIPMENT:

The electronic oscillator and power supply are of standard design and are capable of delivering an alternating current to the transducer in the frequency range from 16,000 to 29,000 cycles/second. The power consumption of the machine is about one kilowatt.

The electromechanical transducer comprises a driving coil and a water-cooled laminated magnetostrictive element. The linear dimensions of the element determine the frequency range of operation of the transducer which is operated near resonance for optimum efficiency. Commercial operations show that these transducers are continuously operable at high efficiency.

The tool holder is a conical element which is attached to the transducer assembly as easily as a drill is inserted in a drill press. The tool holder has a threaded extremity which is screwed into a female counterpart of the transducer whereupon it is tightened with a wrench. Set-up and interchange of different types of tools is a simple and rapid process.

The working head of the tool holder carries an inexpensive steel tool in the shape of the hole, recess or contour desired.

MATERIALS CUT, MACHINED, ETC.:

The following materials can be cut, machined, bored, or threaded by ultrasonics:

Metals	Non-Metals
tungsten carbide	diamond
titanium carbide	synthetic sapphire
zirconium boride	quartz
osium alloys	ferrites
titanium alloys	ferroelectric ceramics (such as barium titanate) and other ceramic materials
hardened tool steel	aluminum oxide
tungsten	onyx
molybdenum	natural stone (such as flint, marble, granite, etc.)
alnico	glass
germanium	boron carbide

TOLERANCES, CUTTING RATES AND SURFACE FINISH:

These are as follows:

(a) Roughing operations are normally carried out with accuracies of 0.002".

(b) Greater accuracies are obtainable using finer grit sizes.

(c) Cutting rates vary with the material being worked and the amount and volume of material removed. Current work is being carried out at cutting rates which are sufficiently high to permit competitive operations.

(d) Finishes in roughing operations are in order of 25 micro inches. Using finer abrasives, finer finishes are obtainable - up to and including a polished surface.

The process involves very low stress and no local heating. Accordingly, there is no thermal cracking, pitting, or burnt color left on the surface. The material being cut undergoes no chemical change, decomposition or alteration of physical properties.

The process has a 100% safety and health record for six years and the equipment can be operated by unskilled help.

SUMMARY:

The most important fact about ultrasonic processing is that it can carry out all cutting, grinding, and machining operations currently requiring the use of diamond wheels, etc. Accordingly, the process naturally lends itself to replacing diamond in these operations.

Specifically, the ultrasonic process is immediately available for the grinding of chip breakers on a commercial scale. Existing equipment is set up to handle this operation on a competitive price basis with effective cutting rates and with low tool cost. Chip breakers are ground ultrasonically in from 30 seconds to 2 minutes with a tool cost under 5 cents and without complicated set-ups.

We suggest that steps be taken to utilize ultrasonic processing in grinding chip breakers.

We also suggest that steps be taken to evaluate other applications where ultrasonics can be used to cut down on the consumption of diamond bort. For example, in the grinding of single point carbide tools.

In conclusion, we should like to point out that ultrasonic machining is not limited to the treatment of carbides or sintered metals but is as readily applicable to machining non-conducting materials such as ferrites, titanates, quartz, synthetic sapphire and the like.

APPENDIX IX

ELECTRO-EROSIVE MACHINING OF HARD METALS AND CARBIDES

By I. Weber and G. F. Nordblom
Frankford Arsenal

The introduction of cemented carbides in the machine tool industry, and their successful use in such tools as extrusion and swagging dies, form tools, single-point tools, and drills has resulted in a rapid increase in the rate of manufacture of parts for military and domestic use. Cemented carbides exhibit extreme hardness and wear resistant properties and, therefore carbide items are usually ground and polished to tolerance with diamond abrasive wheels and lapping dusts.

The machine tool industry of this country is largely dependent on the British diamond monopoly for a supply of industrial diamonds. During a time of war the demand for industrial diamonds would be greatly increased, and this country's present diamond stockpile would be of questionable duration. Any process which would obviate the need for industrial diamonds would, therefore, be of inestimable value.

Recent Russian reports [1,2,3,4,5,6,7,8] indicate that successful machining of cemented carbides and hard metals has been accomplished with various forms of electrical discharges. The Frankford Arsenal is investigating the principles involved in these methods, and is incorporating these principles in the development of a machine to enable the cutting and grinding of single-point and form cutting tools.

The method being investigated is a so-called "contact method", and consists of the cemented carbide connected in a d-c circuit as the anode, and held in contact with a rotating mild steel disc, which acts as the cathode. The tool and rotating disc are immersed in an electrolyte, such as sodium silicate, and a capacitor bank connected in parallel with the electrodes may,

[1,2,3,4,5,6,7,8, - See References]

if desired, be used. At this arsenal the capacitor bank is eliminated from the circuit. Both grinding and cutting may be achieved, depending on whether the carbide is held against the side or the edge of the rotating disc.

Cutting procedures have been thoroughly investigated and the following generalizations have been observed:

1. Pressure on the work has no effect on the cutting time over a practical range.

2. Minimum cutting time is obtained with sodium silicate as the electrolyte, and cutting time decreases with increasing sodium silicate concentration. Other electrolytes are inferior to sodium silicate in both respects.

3. Cutting time decreases with increasing current. However, little is gained by going beyond 100 amperes.

4. Cutting time decreases with increasing peripheral speed in the range, 10 to 40 ft/sec, investigated. Beyond this range there is evidence that cutting time tends to increase with increasing peripheral speed.

5. Cutting time decreases with decreasing wheel thickness.

6. Cutting time is not affected by the hardness of the work piece, but is affected by chemical composition.

In cutting procedures it has been concluded that the method is predominantly an arc cutting process. If a gap is maintained between the rotating disc and the work, the only phenomenon occurring is electrochemical, and is represented by the formation of a silicate film on the anode. There is no possibility for a self initiated spark-over, since the voltages seldom exceed 20 volts. In actual practice a gap between the electrodes is constantly being opened and closed as a result of natural vibration of the apparatus. At the moment the two electrodes separate, an arc is initiated and is maintained until quenched

either by too large a gap distance or by the sodium silicate solution. The arc is of relatively long duration, and because the arc has a high integral temperature, erosion of the anode is predominantly a thermal effect.

During one cycle of natural vibration, the following phenomena occur consecutively: arc erosion, electromchemical deposition of a silicate film on the anode, and direct short circuit. Deposition of a silicate film on the anode is necessary for directing the forces of erosion towards the bottom of the cut, which is kept clean by the rotating disc.

The application of the method to a grinding procedure has not yet been thoroughly studied at the Frankford Arsenal. However, there is no reason to believe that the method, as used in grinding, is purely electroarcing. It is very likely that the principles of electrolytic, electrodeposition, electrosparking, and electro-arcing phenomena may all play significant parts to a greater or lesser extent.

Preliminary investigations of grinding with the present apparatus have consistently resulted in surface finishes of about 5 microinch rms., and edges that are sharper and straighter than those produced through conventional diamond grinding. The technique involves the use of the side of a rotating disc, sodium silicate as the electrolyte, and a current gradually decreasing from 20 amperes to one or two amperes over a five minute period.

The Cincinnati Milling Machine Company is manufacturing for the Frankford Arsenal a machine which will incorporate the principles of the method being investigated, and will permit the following operations to be performed:

1. Straight cut-off and shaping
2. Straight, radial and form grinding or polishing
3. Boring
4. Grinding of chip-breakers

Appendix IX-4

After investigations have been completed, it is probable that the machine will be redesigned and simplified for machine shop use. It is estimated that, using this machine, which will permit fine control of all the parameters involved in electro-erosive machining, ground finishes better than 5 microinch rms. will result.

The method can be used successfully on the following operations, which presently require extensive use of diamond bort:

1. Sharpening of single-point tools
2. Grinding single-point tool chip breakers
3. Sharpening milling cutters and broaches (This operation requires a suitable indexing device)
4. Grinding projectile cores
5. Forming of turbine bucket attachments
6. Maching and grinding of compressor discs

It is desired to emphasize at this point, that the method studied at the Frankford Arsenal will alone, except for techniques using abrasives, permit the following operations to be performed in sequence on one machine:

1. Cut-off of chipped or cracked portion of tool
2. Regrind on three faces to a 5 microinch rms. finish or better
3. Grind in a chip-breaker

The use of the method for these operations will result in a saving of time as well as a major saving in diamond bort.

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